Precision Hole Location

FOR INTERCHANGEABILITY IN TOOLMAKING AND PRODUCTION

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PRECISION HOLE LOCATION

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FOR INTERCHANGEABILITY IN TOOLMAKING AND PRODUCTION

by J. ROBERT MOORE

INCLUDING WOODWORTH CIRCULAR TABLES

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PREFACE

If Eli Whitney *could awaken from his eternal sleep, his eyes would open wide, indeed. His once frowned-upon theory of mass-production through interchangeable parts-and-assembly manufacture now provides a standard of living for the United States that is the envy of the world. Special tools so reduce hand labor as to bring many former luxuries within the reach of an ever-widening consumer public.*

During the 150 years which have elapsed since Whitney's day, every conceivable product has been mass-produced through interchangeable parts-and-assembly methods — except the tools themselves *which made this possible.*

The generations of toolmakers who followed Whitney have constantly advanced the science of achieving volume production of metal, plastic and wood products, but only now have they reached the point where they can apply the same principles to their own work. The ability to mass-produce special tools, dies, fixtures, gages and molds under stringent accuracy requirements is the most significant industrial advance since man grasped the ability to mass-produce end products. What this will mean during the next 150 years defies the imagination.

The single purpose of this book is to show in full detail how one highly important phase of the toolmaking job — accurate hole location through engineered methods — promotes interchangeability at the very source of all mass-production, namely the tool.

J. Robert Moore

Fig. 1 — Products of modern mass production. Competitive incentives compel use of principle of interchangeable parts and assembly.

INTRODUCTORY

THE intensified interest in technical training brought about by World War II revealed a crying need for more and better textbooks dealing with modern machine shop methods and machines. Continuing dearth of up-to-the-minute literature on tooling and machining methods now is one of the main reasons why the postwar "revolution in machine shop practice" has not materialized as rapidly or as extensively as was predicted.

Under these circumstances, it is a responsibility as well as a privilege to write this introduction to a book which — because it gives the latest information about the basic subject of "hole making" — can do much toward promoting the revolution in machine shop practice which, in turn, will mean more and better goods for more people and at the same time more and better jobs.

James Watt encountered serious trouble with "hole making" back in 1775 when he undertook to build steam engines. John Wilkinson came to his rescue with a machine which bored Watt's cylinders so that "they did not err the thickness of an old shilling in any part". What was good enough for Watt was not good enough for Eli Whitney and Eli Terry and Seth Thomas and other founders of interchangeable manufacturing here in America. Their work had to be to "thousandths", even though they did not dimension it that way. Then about the time of World War I, hole specifications to "tenths" began to appear. And now commercial hole dimensioning is being done in "millionths".

Throughout the years, many ingenious expedients have been evolved by gunsmiths, watch and clock makers and other skilled artisans, in efforts to keep pace with these ever-tightening limits. With the advent of "millionths", however, those expedients no longer were adequate. The relatively recent introduction of the Jig Borer, and the even more recent development of the Jig Grinder, have saved the situation by making exact (and repetitive) location, generation and fine finishing of round holes matters of scientific machine-setting instead of rule-of-thumb trick setups.

That is what this book is about. It goes into the history of the old methods merely as a prelude to a complete exposition of ways and means of applying Jig Borers and Jig Grinders successfully and profitably, to a wide variety of tool, die and production operations demanding precision hole locating and finishing. My good friend J. Robert Moore has profound, first-hand knowledge of these subjects. He has writing ability. He has stick-to-it-ive-ness — and how one needs that during the "pants-to-chair" ordeal of technical writing!

For many years, Bob has been associated with his elder brother, Richard F. Moore, president, The Moore Special Tool Company, Bridgeport, Conn. I know of no other company which has so extensive a knowledge of hole location methods. Bob's experience has included precision tool and die work, grinding precision lead screws, and engineering development and commercial applications of Moore Jig Borers and Jig Grinders. He was graduated from Clark University, Worcester, Mass., where he laid a solid scientific foundation for his tool engineering career.

This book does credit not only to its author but also to those who cooperated with him. Richard Moore and Fred Wittner, of Fred Wittner Advertising, deserve special mention — Dick as sponsor of the undertaking, Fred as consultant on organization of material and supervision.

Having had a preview of this book chapter by chapter, here are my convictions. Copies should be distributed throughout the metalworking industry, also to all educational institutions concerned therewith. The book deserves study by machinery builders, production executives, tool engineers, product designers, tool and die makers, technical and trade school students, and apprentices.

In other words, *Precision Hole Location* is "required reading" for all who aspire to up-to-the-minute acquaintance with the basic principles of the American, or interchangeable, system of manufacturing.

GUY HUBBARD
Machine Tool Editor, STEEL Magazine

Cleveland, Ohio
June 1, 1946

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Fig. 2 — Tools, too, can be produced on interchangeable parts-and-assembly basis. Models, gages, drill jigs, dies and templates represent average run of tool work. Precise location of holes is major part of job.

Chapter I

HOLE LOCATION — BUGABOO OF THE TOOLMAKER

THE ENDLESS problem of accurately locating holes is a major source of irritation to the tool, die and model maker. He faces the problem daily — on gages, drill jigs, dies, fixtures, models and experimental work. Practically every toolmaking job today requires accurate holes, Fig. 2, to guide drills or reamers, to locate or guide punches through dies, or for pins to locate the work.

Strangely enough, very little has been done, until recent times, to relieve the toolmaker of this headache. Machines for other parts of his job, such as lathes, for boring or turning rounds, planers, shapers and milling machines for developing flats or shapes, and machines for drilling holes were conceived long ago, and have enjoyed continuous development and improvement. The problem of putting two or more holes into a workpiece *correctly spaced*, however, has been given little attention. Improvements in the practices for doing this have lagged far behind other machine processes. The reasons for this lag are not readily seen. It may be that the costs of this part of the job have been so obscurely buried that the incentive to progress has not been recognized. As a result, the toolmaker has plodded along the same road his grandfathers followed.

Conventional methods for locating holes, such as buttoning, wiggling and indicating, are slow and tedious. The doubtful practices of drilling and counterboring from layouts, and drilling and reaming through bushings, are short cuts improvised by the toolmaker to save time. None produces dependable results except through the exercise of great skill and patience.

This problem is aggravated by the fact that after he has done a beautiful job of boring the holes, heat-treating usually results in distortion or decarburization, or both. After hardening, he must correct the holes all over again by the still more tedious process of grinding. He must either do this or accept the errors and unreliable performance of a tool in the unground condition. This problem is in the front of his mind when he specifies materials, and leads him to make compromises. Instead of specifying the hardest, longest-wearing materials, he foresees the inevitable heat-treating difficulties and, seeking to minimize distortion or decarburization, even

at the expense of long life, employs inferior materials.

Gage bodies and drill jigs, for example, are often bored and fitted with hardened bushings to avoid heat-treating. This is inadequate for work involving high accuracies or high production, since soft bodies are distorted by the insertion of bushings and become battered by abuse. Replacement of bushings wears the sides of the bored holes.

The widespread use of hardened bushings in soft bodies is in reality a compromise, employed because heretofore no convenient way has been available for correcting the holes by grinding. Modern methods eliminate the need for this compromise. Bodies can now be hardened, ground and fitted with bushings without danger of scoring or distorting the holes in the bodies.

Other types of tools do not permit this compromise. To give good service, the cutting edges of blanking and piercing dies must be hardened. Although some steels are tailored to harden with a minimum of distortion, they are not ideal for all jobs. When cutting thin, hard, or abrasive materials such as razor blades or electrical laminations, the dies must be made from special wear-resistant steels and must be ground all over, including the inside of all holes, to give anything like satisfactory performance.

The choice, then, is precarious; either course is costly. If the toolmaker elects to make a thoroughly good job, the *tool* is expensive. If, on the other hand, he elects to compromise, either in materials or workmanship, subsequent tool maintenance will make the *product* expensive.

Thus management, as well as the toolmaker, has an interest in the problem. Tooling-up is time-consuming. During this period no return can be expected on invested capital. Management's impatience further influences the toolmaker toward compromises, with the result that, when finished, the tools run improperly or fail after short runs. Frequent breakdowns and parts spoilage waste manufacturing facilities and hold up production. Sometimes the toolmaker is blamed; sometimes the censure is applied to the production department. Seldom specified is the true fault: lack of the proper equipment in the toolroom, where most of the troubles originate.

At the other end of the scale, the apprentice also is harassed. He soon learns that a large part of the toolmaker's work consists of locating holes. He is confused by the many complicated and contradictory methods employed. When he asks questions about this important phase of toolmaking, he gets about as many answers as there are toolmakers. Each toolmaker, he finds, has developed tricks and practices of his own, usually difficult to teach because of the high degree of personal skill and long experience required. This bewilders the apprentice, who frequently wonders "why he ever started in this business anyway".

The toolmaker can appear to evade the hole locating problem:

1. By relaxing the tolerances in the final product.
2. By relaxing the skill and care that he puts into the making of the tool.

These evasions do not *solve* the problem. Men acquainted with the present-day demand for high accuracies know that they are not permitted. On the contrary, the tendency is toward constant tightening of tolerances and better workmanship.

There are good reasons for this. Each manufacturer tries to outdo his competitors in delivering more and more accurate products to his customers, and at lower cost, Fig. 2. The only way to keep his product accurate is to tighten his tolerances. To promote lower cost through mass-production methods, he must maintain strict interchangeability between parts.

Nor can the toolmaker relax his standards of workmanship, since the end product of the tool can never be better than the tool. Even assuming that there are places where manufacturing tolerances may be relaxed, the tool must be kept sharp and clean — cutting with a minimum of expense. To insure this, punches must be aligned perfectly with dies, and all cutting edges ground.

Compromises such as those mentioned in preceding pages, therefore, do not solve the problem at all. They evade it. They contribute nothing.

A more far-sighted view is that taken by engineers of The Moore Special Tool Company. Product engineers and toolmakers are encouraged toward tight tolerances and good workmanship. Rather than evade the problem, they believe that the *real solution* is to put into the workman's hands tools with which the desired results can be achieved.

We propose to analyze the toolmaker's hole location problem and to offer the benefits of the experience and advanced thinking which have produced the now-recognized methods for removing it from the "problem" category.

In so doing, we find that the benefits are not limited to merely solving the problem. They actually raise the quality level of the toolmaker's work, not only in the individual shop but in the toolmaking industry as a whole. The productive capacity of the entire industry increases, with the result that pay envelopes are fatter, working conditions are improved, and the toolmaker's work acquires new dignity.

Men who study tools from the long-range point of view recognize that this is an important turning-point in the history of toolmaking. Although promoted by the toolmaker and universally accepted in mass-production, interchangeability has never been employed to any great extent *by the toolmaker in his own operations.* A primary purpose of this book is to show how he can now do so.

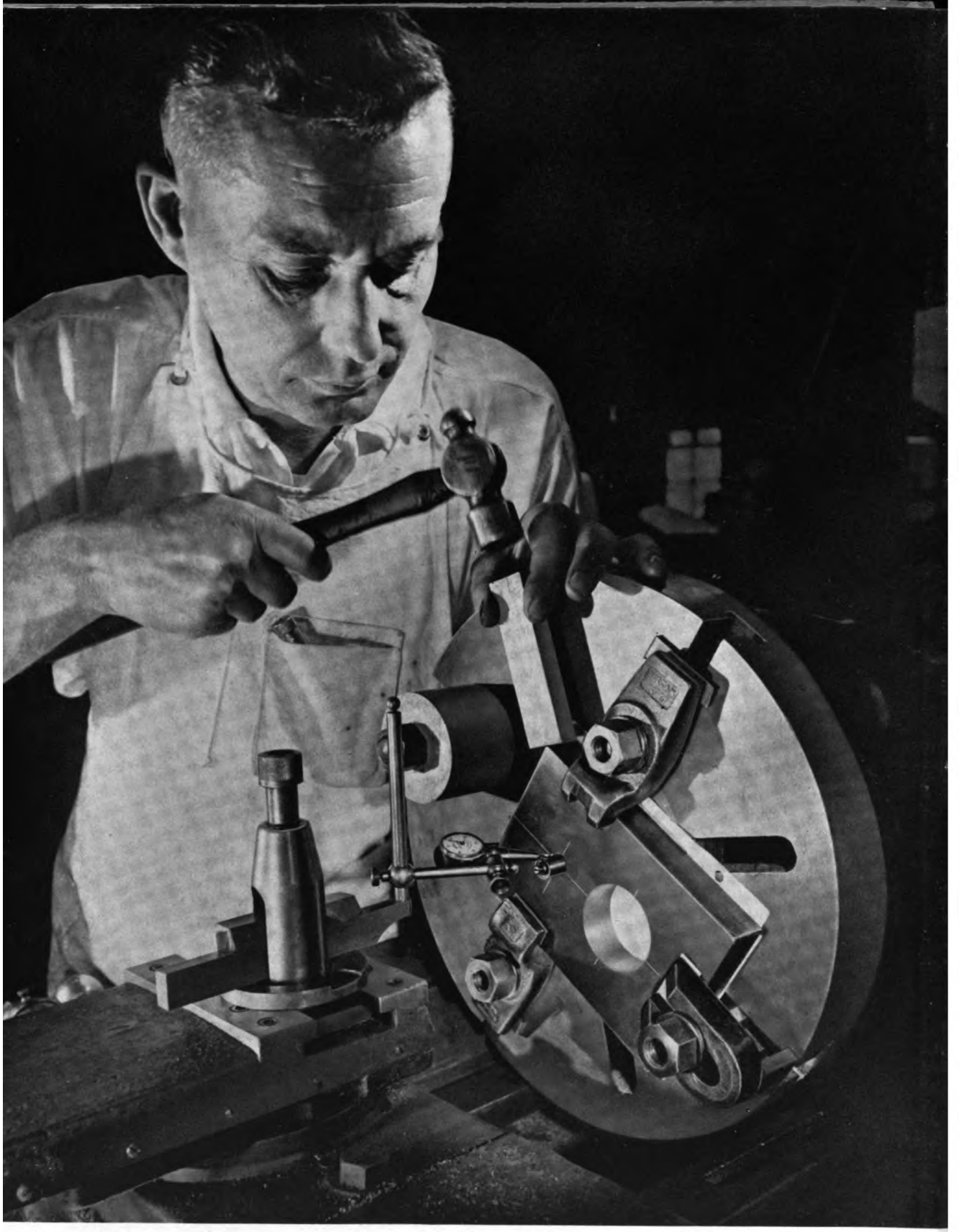


Fig. 3 — Toolmakers have always managed to get holes in, somehow . . . But at what price!

Chapter II

THEY GOT HOLES IN SOMEHOW

MODERN hole locating machines and their contribution to toolmaking cannot be fully appreciated without understanding what the toolmaker had to do before they were created.

The reader might well ask, "Why all this fretting about hole locating? Toolmakers have always managed to put holes in the right place, somehow. Why do you now claim that modern methods are so much superior to those of the past?"

The reason for this question is readily found. Specialized hole locating machines, such as the modern Jig Borer and Jig Grinder, are so recent that many toolmakers and manufacturers do not fully appreciate their potentialities. Although the hole locating problem has irritated the toolmaker for many years, it is surprising that no real engineered solution has been developed until recent times; the Jig Borer, in 1917, and the Jig Grinder even more recently, in 1940, both significantly during war periods. These machines are not yet widely enough known. Toolmakers in many prominent manufacturing plants today are still using methods employed by their grandfathers.

While it is true that toolmakers "managed to put holes in, somehow", their methods left much to be desired in economy and accuracy. This can be recognized by a thorough analysis of these methods.

There are three separate, fundamental steps in the hole location procedure, and these should be kept in mind throughout our discussion. Nor does the introduction of modern machines alter the situation. While machines have added enormously to the overall efficiency by making each of the steps more convenient or more accurate, or both, the necessity for the three steps still exists. They should be regarded as three separate parts of the job.

Tabulation of these three fundamental steps, together with some of the methods for performing them, will clarify their relationship in the reader's mind:

Step I. Locating — or establishing the desired position of the finished hole in the workpiece.

1. Layout. Making lines or prick-punch

marks directly on the surface of the part to be drilled.

2. Buttoning. Named after the toolmaker's "button", a hardened steel cylinder attached to the workpiece. The button is located on the workpiece concentric with the desired hole, and later is trued up with the center of the spindle of the machine used for the boring operation.

3. Transfer. Used where exact desired locations are not known, but where the relative locations of corresponding holes in two pieces must match each other. Spotters may be used to establish pickup points on the workpiece, or, parts being clamped together, holes may be drilled or reamed through the workpiece, using the original as a guide, or jig. In a variation of the transfer method used in watch and clock factories, the holes in a "master plate" attached to the workpiece are trued up in a lathe before boring the workpiece.

4. The coordinate location system. The long search for an efficient locating method to eliminate layouts and buttons has led to the development of what we now call the coordinate location system. Definite measurements are made by devices *extraneous to the workpiece.* Transferring is eliminated in favor of *working to known dimensions.*

Step II. Cutting — or removal of material by drilling, reaming, boring, grinding, or lapping in such a manner as to insure that the resulting hole will be in the desired pre-determined position, and to size.

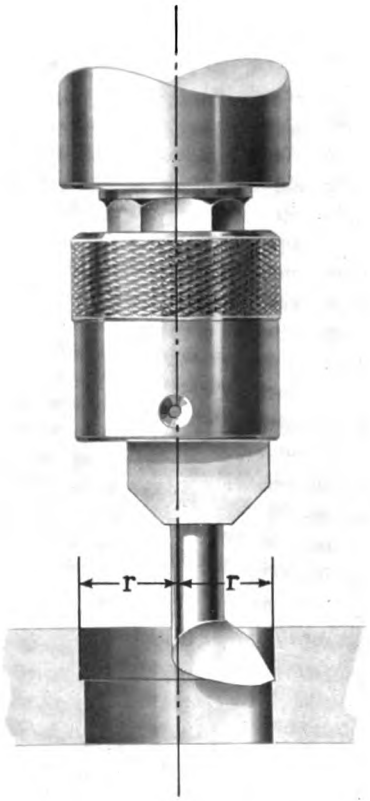


Fig. 4. — Single-point boring — the most accurate finishing method. Surface is generated by rotation about axis. Either workpiece or tool may rotate. Final accuracy and finish depend upon rigidity and accuracy of spindle and cutting tool.

1. Single-point boring, Fig. 4, the most accurate means of finishing holes in soft steel, since it is geometrically correct. Geometry defines a true circle as the "locus of all points at a given distance from a fixed point". Since the point of the cutting tool is always the same distance from the axis of rotation of the spindle, the surface generated is a true circle, or

cylinder. Cutting pressure springs the tool somewhat, of course. Its effect, however, for all practical purposes, is eliminated by sharpening the tool carefully and taking light cuts when finishing.

2. Drilling, counterboring, reaming. These terms are not synonymous, but, for our present purposes, they all have in common the feature that location of the cutting tool is guided entirely by the material being cut.

3. Drilling and reaming through a bushing — similar to No. 2, but using some extraneous means such as a hardened bushing to guide the cutting tool.

Neither of these two methods is accepted as regular practice on high-precision work. Both are employed by toolmakers as short-cuts, to evade the tediousness of wiggling, or buttoning, and single-point boring.

4. Grinding. Hardened steel cannot be cut by single-point boring; it must be ground with abrasive wheels or diamond-charged mandrels. Grinding is the most accurate method for locating holes in hardened work. The grinding wheel is supported as rigidly as possible by an independent spindle. Grinding pressure, like boring pressure, also springs the grinding spindle. Fine finishing cuts, however, eliminate this effect more than boring, especially if grinding wheels are freshly dressed.

5. Lapping or honing. This is similar to grinding only to the extent that hard abrasive particles are used as the cutting agent. The similarity stops here, however. A clear distinction is made between grinding and lapping in that grinding is employed to establish the location of a surface, while lapping and honing merely improve the surface finish without altering location. The already established hole guides the lap, or hone. The small amount of stock removed by this process is removed uniformly. The hole is slightly enlarged and smoothed but *not altered as to location.*

Step III. Checking or Inspection — Some method for determining, after locating and cutting, whether the finished hole is in its correct pre-determined position. So many different conditions are met in this part of the job that it is difficult to enumerate them here. Instead, examples will be shown to illustrate the commonly used methods. Rapid and efficient means are *fully as important* for this part of the job as for either of the other two. It will be seen that the modern principle of coordinate location plays a predominant part.

The three basic steps in hole locating can be accomplished in many ways. Different methods or combinations are employed for different purposes, the selection depending upon the results desired. Some are rapid but inaccurate; others are accurate but slow and tedious. You get what you pay for. The final result depends upon

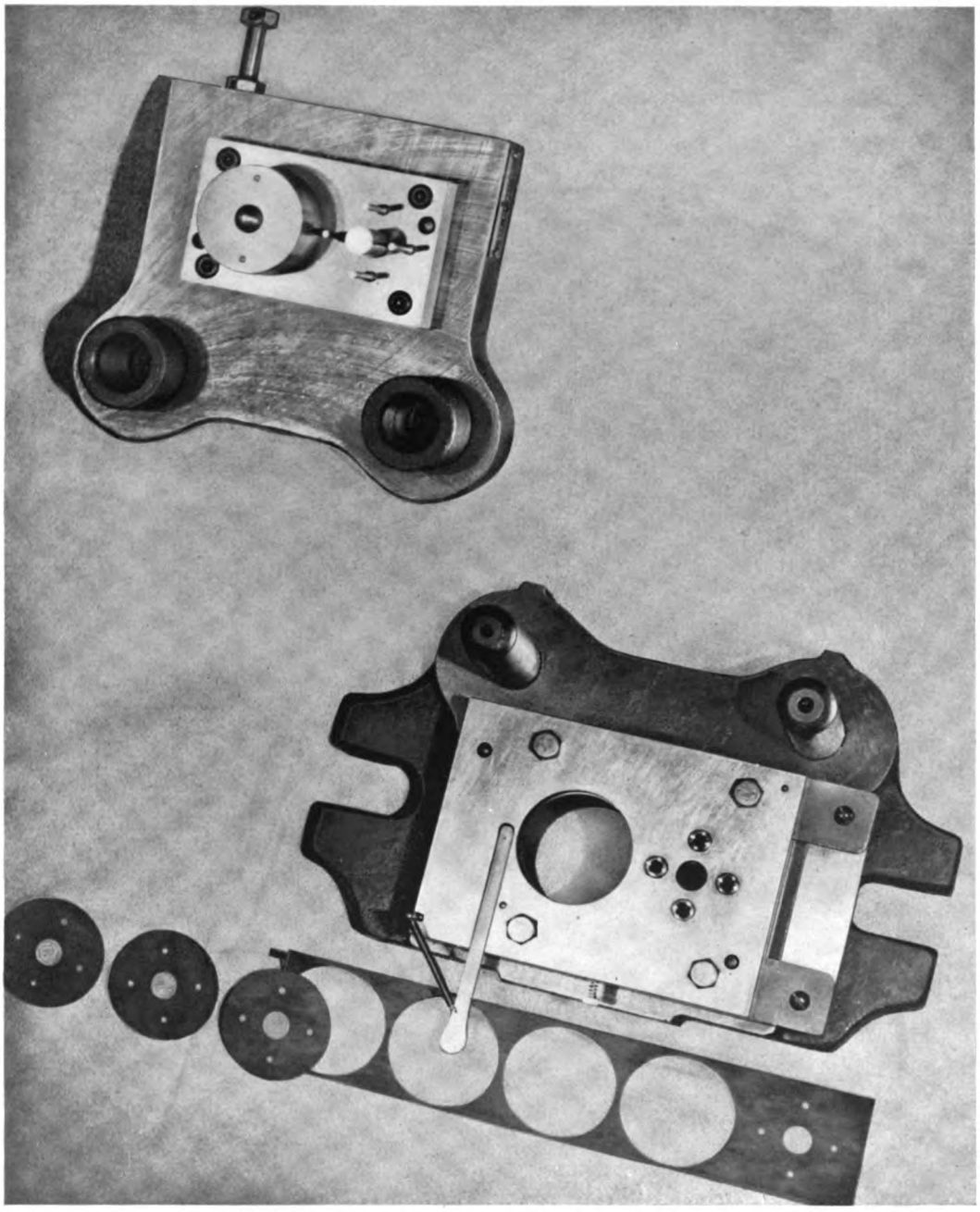


Fig. 5 — Typical die illustrating hole location problem. This die will be used as an example throughout book. At some stages it will be assumed that the die will cut thick material and be made to broad tolerances. At other times die will be assumed to require high accuracies. The reader should pay close attention to the text to follow the requirements at any particular moment.

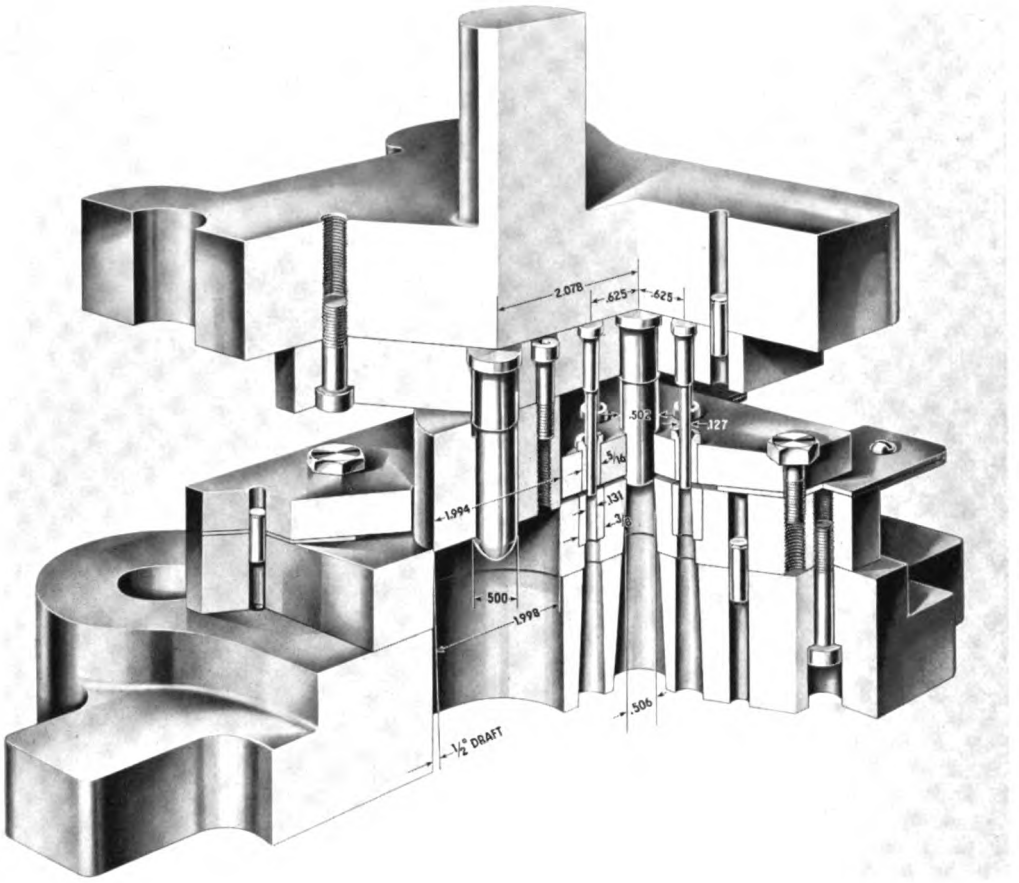


Fig. 6 — Dimensional details of die shown in Fig. 5. Note clearances between punch and die diameters. At this point, die is used for cutting thick stock.

skill, care, and last but not least, *the equipment employed.*

Some methods of *locating* are better adapted to certain *cutting* procedures than others; sometimes combinations of various methods are employed. The advantages and disadvantages of the different methods are explained through a specific example, such as a typical piercing and blanking die, Figs. 5, 6 and 7. This die, from a hole location standpoint only, will be used to

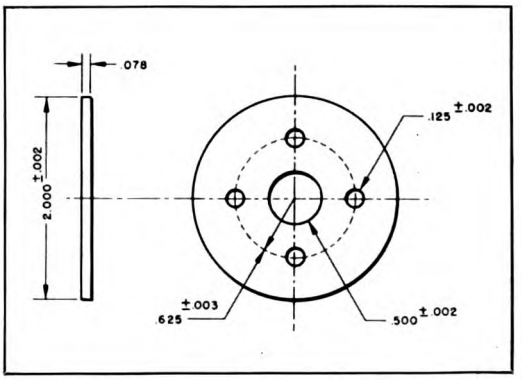


Fig. 7 — Piece part to be made in die shown in Figs. 5 and 6. At this point, it is assumed that the material is thick and that tolerances are broad.

Fig. 8 — Squaring up die block preparatory to layout. Since the edges of this block will be used for layout purdoses, it is imperative to square it very accurately. Use of modern hole location machines eliminates the necessity for this tedious operation on a simple die such as this one.

illustrate the best-known principles. At this point, the die is made to cut comparatively thick stock (.078″), and to produce a piece part with broad locational tolerances, Fig. 7.

Fig. 9 — Laying out die block with combination square and scriber. This is not a generally recognized method because of its inherent inaccuracies.

The first part of a die to be made is the die block itself, Fig. 8. Since locational dimensions are usually given in rectangular directions, the block should be squared up by grinding all over. This is not important to the operation of the finished die, but is necessary to establish bases for layout.

Laying Out — A combination square and scriber can be used for this, for results within about .005″, Fig. 9. Reasons for inaccuracies are easily understood. In the first place, the lines on the scale are too coarse to permit of accurate settings, and

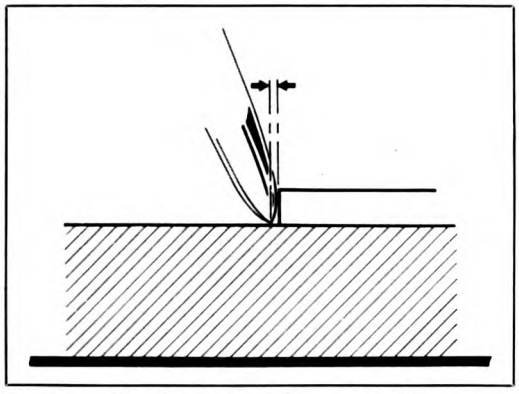


Fig. 10 — The "furrow", or line, scribed by a scriber at the end of a scale, is not flush with the scale, but some distance away, depending upon the sharpness of the scriber.

the sighting is done along the edge of the body of the square. In addition to the error introduced by the setting of the scale, another is created by the relation of the scriber to the work and the edge of the square, Fig. 10.

The surface gage can be used when somewhat more accurate results are desired, Fig. 11. This can be set, by compari-

Fig. 11 — Laying out die block with surface gage. This method is somewhat more accurate than the combination square because of better accessibility of scale divisions and scriber point.

Fig. 12 — Setting surface gage against scale, requires a good eye and steady posture, especially when interpolating between scale divisions. Eye must be on same level as scriber, to avoid parallax.

son with a scale, to closer limits than a combination square, because the lines on the scale are not covered up, Fig. 12, and does not introduce an error from its action against the end of a scale, as in Fig. 10. Best accuracy of the surface gage is approximately ±.002″ to ±.003″.

Three other layout tools are shown in Fig. 13. The height gage is the most convenient and most frequently used. It can be set to much closer limits than either the combination square or the surface gage. A vernier permits reading to "thousandths" and estimating "half-thousandths". It can be set fairly easily to within ±.0002″ or ±.0003″. The planer gage can be set with micrometers within somewhat closer limits than the height gage, if care is used. The gage blocks attain very close limits, since they are the standard of accuracy in most toolrooms.

Part of the value of this high accuracy is lost by the shape of the scriber, a fault common to all three of these tools. To maintain a consistent relationship of the scriber, one face is left flat and the other face ground and lapped to a sharp wedge. The center of the line, therefore, is not central with the bottom face of the scriber; instead, the bottom face of the scriber determines the *bottom edge* of the line. When the scriber becomes worn, a con-

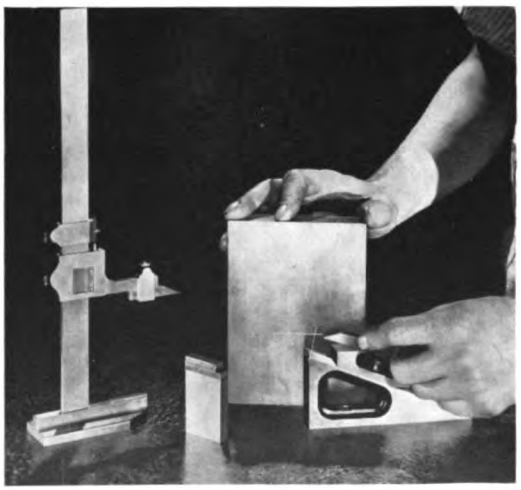


Fig. 13 — Commonly-employed layout tools. The wedge-shaped scribers permit sharpening without changing the location of the bottom edge.

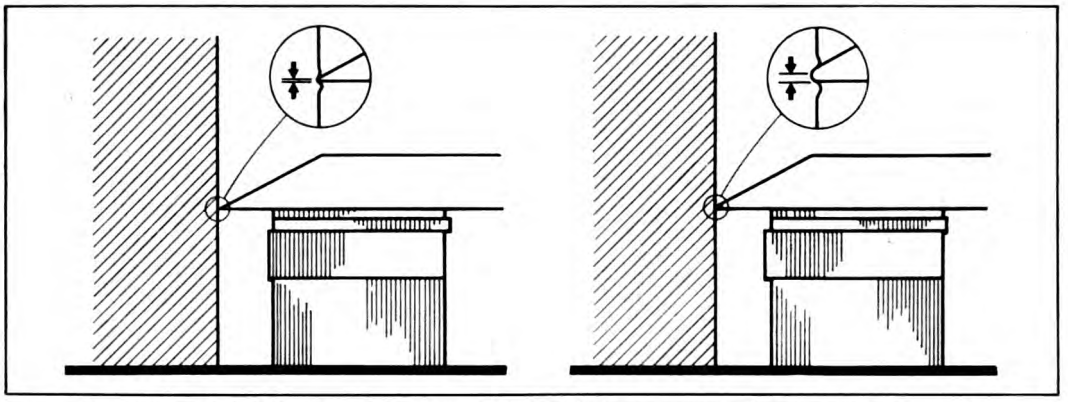


Fig. 14 — The height gage, planer gage, and gage blocks are recognized as the most accurate of the layout tools. However, they have in common the fault that dulling of the scriber during use raises the position of the line. To produce the best results, the scriber must be kept sharp.

siderable error is introduced, Fig. 14. The error is always in the same direction, but its amount varies with the condition of the scriber and the depth of the line. Gage blocks, the most accurate means, permit scribing fine lines within ±.0002″. This does not represent the accuracy of the finished hole. Subsequent steps introduce additional errors. Care and skill must be employed throughout the process to insure the best results.

Assuming that the lines have been laid out on the die, we can now consider cutting methods. To illustrate a wide variety of cutting methods, some of which will not produce too accurate results, we shall still assume that locational tolerances closer than .002″ to .003″ are not required. We shall change this assumption later to show methods required for higher accuracy.

Prick-punch marks are required at the intersections of the scribed lines. As soon as an attempt is made to prick-punch the block, additional difficulties appear. The prick-punch will not lie in the center of the line because both sides of the line are of different steepnesses, Fig. 15. The prick-punch must be accurately ground to prevent it from moving due to its own irregular shape. Fig. 15 further emphasizes the importance of keeping the scriber good and sharp, and of scribing *fine* lines. The shallower the lines, the less the error introduced by prick-punching.

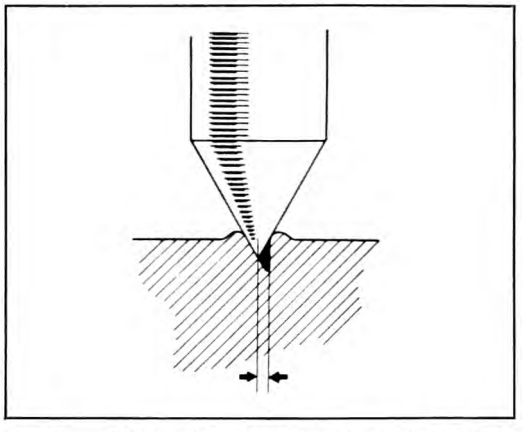


Fig. 15 — Additional error introduced by prick-punching. The most accurate layout method, employing wedge-shaped scriber, unfortunately introduces largest error in prick-punching; two sides of scribed line are of unequal steepness. Error is minimized by scribing ***fine*** *lines.*

Fig. 16 — Prick-punching die block preparatory to wiggling or drilling. Fig. 15 illustrates uncertainty of prick-punch accuracy.

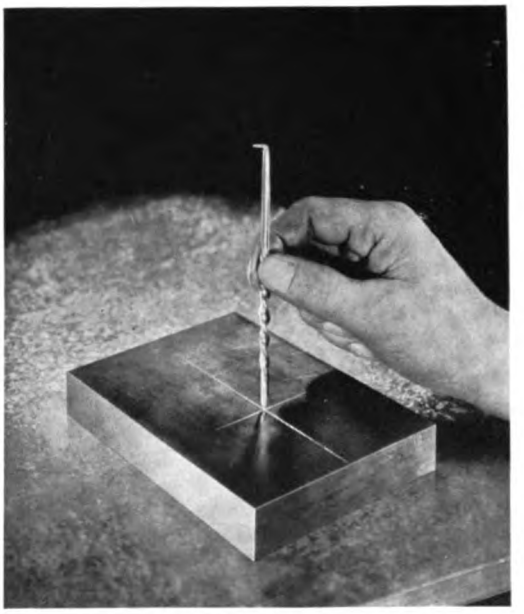


Fig. 17 — Rotating prick-punch with more acute angle than massive punch for hammering. More sensitive "feel" permits easier alignment.

The prick-punch is struck very lightly with a hammer, to make a mark about 1/64″ in diameter, Fig. 16. Examine carefully with a magnifying glass to make sure the mark is central with both lines. This is a matter of visual estimation, and cannot be done within extremely close limits. ±.001″ or ±.002″ is about the best that can be expected.

The ordinary prick-punch is somewhat massive, and cannot be ground to too sharp a point. It must have strength to resist a hammer blow without chipping. This increases the difficulty of centering it in the fine lines.

To overcome this, and to avoid the necessity for making the lines too coarse, a rotating prick-punch is sometimes used, Fig. 17. This is a light piece, and "feels" its way into the line easily. Since it is not intended to be struck with a hammer, it can be ground to a much more acute point, Fig. 18. It is usually made from a piece of twisted flat or square stock. Downward pressure of the fingers sliding along it causes it to rotate, wearing a slight in-

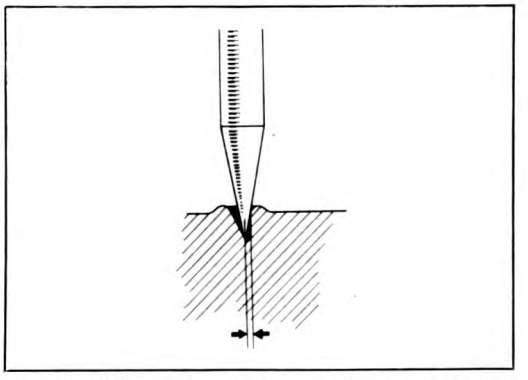


Fig. 18 — The acute angle of the rotating punch finds its position readily in a fine line. The mark made by this punch, however, is not large enough to accommodate a wiggler or start a drill. It must be carefully enlarged with a regular prick-punch and hammer.

Fig. 19 — Picking up prick-punch mark with pump center and indicator. Tediousness of this operation is recognized from uncertainty of attaining exact location by rapping with hammer.

dentation in the workpiece. This type of punch will not make a large enough spot to accommodate a wiggler or start a drill; it is enlarged with the standard prick-punch and hammer. The enlarging must be done carefully, and must be examined with a magnifying glass, to be sure the original position is not disturbed.

Single-Point Boring — The blanking hole and the center piercing hole will be single-point bored. This is the orthodox cutting method, and should be explained first.

In boring cylindrical holes, either the workpiece or the tool may rotate; the toolmaker employs whatever machines and tools are most conveniently available. The locating is usually done by wiggling or buttoning. These principles will be illustrated in the boring of the blanking hole and the center piercing hole in the die. Since these holes are tapered, the cutting tool must traverse a path not parallel to the axis of the hole. In this case, therefore, the boring cannot be done in a milling machine. The workpiece will be rotated in a lathe.

Wiggling — Since the die is laid out and prick-punched, one hole can be "wiggled" (or indicated) to position on the lathe faceplate. With the die roughly clamped in place, a spring wiggler or pump center is inserted into one of the prick-punch marks. When the lathe spindle is turned, an indicator held against the wiggler shows whether the prick-punch mark is in the center of rotation of the spindle. If not,

Fig. 20 — Single-point boring blank hole in die. Note different-sized straps holding work to minimize out-of-balance of workpiece on faceplate. Note that the cutting tool is not guided by the material being cut, but is independently supported. Taper is achieved by feeding the tool on an angle with respect to center of rotation.

the die is tapped around on the faceplate until it runs true, Fig. 19. The straps holding the work are now tightly clamped, and the die is drilled to roughly remove the stock, then bored to size and taper with a single-point tool, Fig. 20.

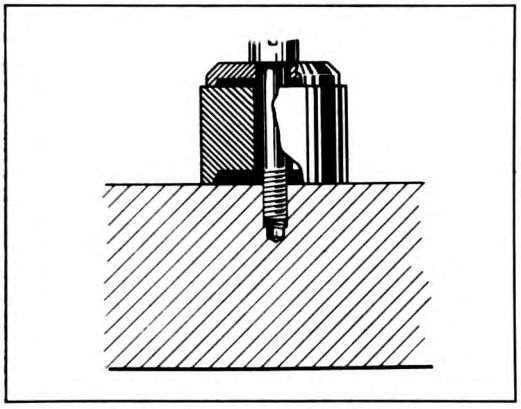


Fig. 21 — Sectional details of toolmaker's button. Screw holds button to work, but clearance between screw and button permits button to be aligned in correct position by rapping it around until measurements show its position to be correct.

Buttoning — Toolmaker's buttons are used where higher accuracies are required than can be expected by wiggling. The button is attached by means of a screw in a small hole drilled and tapped into the face of the die roughly in the center of the desired finished hole, Fig. 21. The screw is loose enough in the button to permit it to be tapped with a brass hammer until its center coincides with the center of the desired finished hole. Measurements are made with the height gage or by comparison with piles of gage blocks, Fig. 22. The tediousness is emphasized by the fact that the button must be aligned in two directions. A rap given in one direction frequently changes its position in the other direction also. Sometimes it takes a good many minutes to get the button finally set. After the button is set, the screw must be tightened securely. This sometimes shifts the button again, so it must be carefully re-checked. The die block is roughly fastened to the lathe faceplate, and indicated and hammered around until the button indicates true with the lathe spindle. After the die is properly located, counterweights must be fastened to the faceplate to minimize centrifugal displacement, Fig. 3. The button is now removed, and the hole drilled and single-point bored in the same manner as in Fig. 20. If the workman is fortunate and the button or the work has not accidentally shifted during the ham-

Fig. 22 — Locating button on die block. This is an extremely painstaking operation since button must be aligned in both directions. See also Fig. 3.

mering or boring, and if the lathe spindle is in excellent condition, this method may produce results within ±.0005″.

Drilling and Counterboring from a Layout — This is not considered good, orthodox practice, but is employed as a short-cut. Even in skillful hands, it is admittedly less dependable than single-point boring. Its results are somewhat of a gamble, but it is rapid, and is satisfactory for cases where extremely high accuracies are not required. Tapered holes, of course, cannot be done in this way. Although a great many tools are required, they are simple and can be used repeatedly. The only machine needed is an ordinary drill press.

Since we are at present working under the assumption that accuracies no better than ±.002″ or ±.003″ are required, we can illustrate this by drilling and counterboring the four small piercing holes in the die.

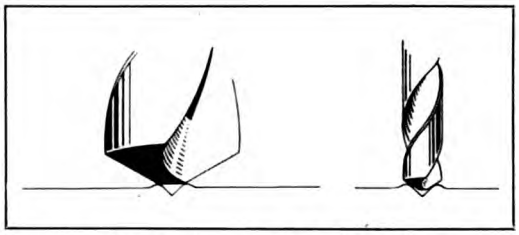


Fig. 23 — Left, too-large drills should not be started in small prick-punch marks. Flat web of drill will obliterate mark upon its first contact. Right, since the prick-punch mark is intended to guide the drill, the drill should be small enough to be well supported.

For accurate results, a large drill should never be started in a small prick-punch mark. The first contact of the flat web of the drill will obliterate the mark, Fig. 23. The best start is made when the prick-punch mark entirely surrounds the drill, or at least comes well up on the cutting edges. Since the eye cannot readily estimate the position of a large prick-punch mark, a small mark, and, therefore, a small drill, must be used to start the hole. If the first drill is about .025″ or .030″, the prick-punch can be .020″ to .030″.

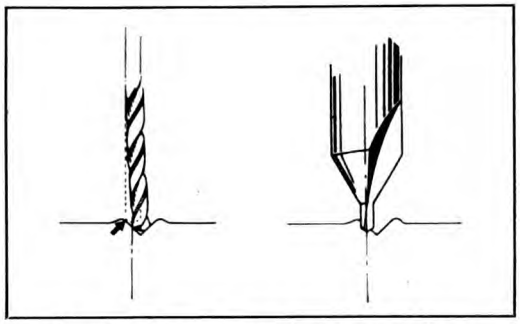


Fig. 24 — Since the position of the hole is to be determined by the prick-punch mark, a slender twist drill should be used to start the hole. A rigid drill, if not in perfect alignment, will influence position of hole. Slender drill, at left, will follow prick-punch mark. Rigid, combination drill, right, will cut into side of prick-punch mark instead of being guided by it.

An ordinary twist drill should be used to start the hole. The center, or combination drill should *not* be used. The reason for this will be apparent from Fig. 24. The position of the hole is to be determined by the prick-punch mark, and a slight misalignment between the drill and the mark is compensated by the flexibility of the drill. The slender twist drill will bend and center itself in the prick-punch mark, whereas the rigid center drill will not. The rigid center drill will undesirably influence the position of the hole in the direction of the original misalignment between spindle and work. This should be carefully noted, since a method of drilling with a center

drill will be later described, see pages 105 and 132, where use of a rigid spotting tool is desirable. The distinction between the methods is that, at present, we are determining the position of the hole from the prick-punch mark, and we want to eliminate all possible influence from misalignment of the spindle or from any other source.

Since the starting drill is flexible, it will not follow through vertically, and should not be permitted to go too deep. It should go just deep enough to accommodate the length of the pilot of the counterbore to be used, plus enough to get the second counterbore or drill well started.

The starting drill should now be followed by another drill, acting as a reamer in order to bring the hole to some predetermined size. This is important, since the pilot of the counterbore must fit its guiding hole closely.

Let us now assume that the hole has been reamed with a 1/32" drill, and is now ready for the first counterbore. At this point it is necessary to decide what size increments are to be used in bringing the hole up to 3/8". Two factors must be considered:

1. As few steps as possible must be used, since unpredictable errors are introduced at each step.

2. The difference in size between each step and the next should not be too great, because of the fragility of the counterbore pilot. The cutting action of the counterbore exerts a terrific sideways force against the pilot, tending to break it off. The cutting diameter of the counterbore should not be more than three to four times the pilot diameter on sizes up to 1/8", or more than two to three times on sizes between 1/8" and 1/2".

Since these factors are contradictory, they must be compromised. Probably the best series of increments in this case would be from 1/32" to 3/32", from 3/32" to 3/16" and from 3/16" to 3/8".

Fig. 25 shows required steps in locating holes by layout, drilling and counterboring. Each step introduces errors; the average overall results will probably be within ±.002" if the work is carefully and skillfully done. Each of the four outside holes may be done in this manner.

Inspection and Correction — Although all of the methods for locating or boring holes are not yet described, our die is now ready to be hardened and locations of the holes should be checked. Rough inspection can be made with a scale, but, since it is difficult for the eye to estimate the positions of edges of holes, an indicator is usually employed.

This inspection procedure, although a necessary step in the hole locating process, is tedious and time consuming. A great deal of it, however, may now be eliminated through the use of modern hole locating machines, not only for initial location and boring, but also for checking final results.

1. *Scribed line*
2. *Rotating prick-punch*
3. *Regular prick-punch*
4. *Drill .028″*
5. *Ream with 1/32″ drill used as reamer. This step, like 9 and 13, is taken to insure a good fit for the subsequent counterbore pilot.*
6. *Counterbore .089″*
7. *Same, deeper*
8. *.089″ drill, deeper*
9. *Ream with 3/32″ drill used as reamer. Corners of drills employed for this purpose should be slightly rounded and stoned to a keen cutting edge.*
10. *Counterbore .182″*
11. *Same, deeper*
12. *No. 14 drill (.182″), through*
13. *Ream 3/16″. Although small drills are satisfactory as reamers, large ones do not produce holes sufficiently accurate as to roundness. Fluted or rose reamers should be employed for larger sizes, such as this.*
14. *Counterbore .370″*
15. *Same, to proper finished depth*
16. *Finish ream hole to .375″*

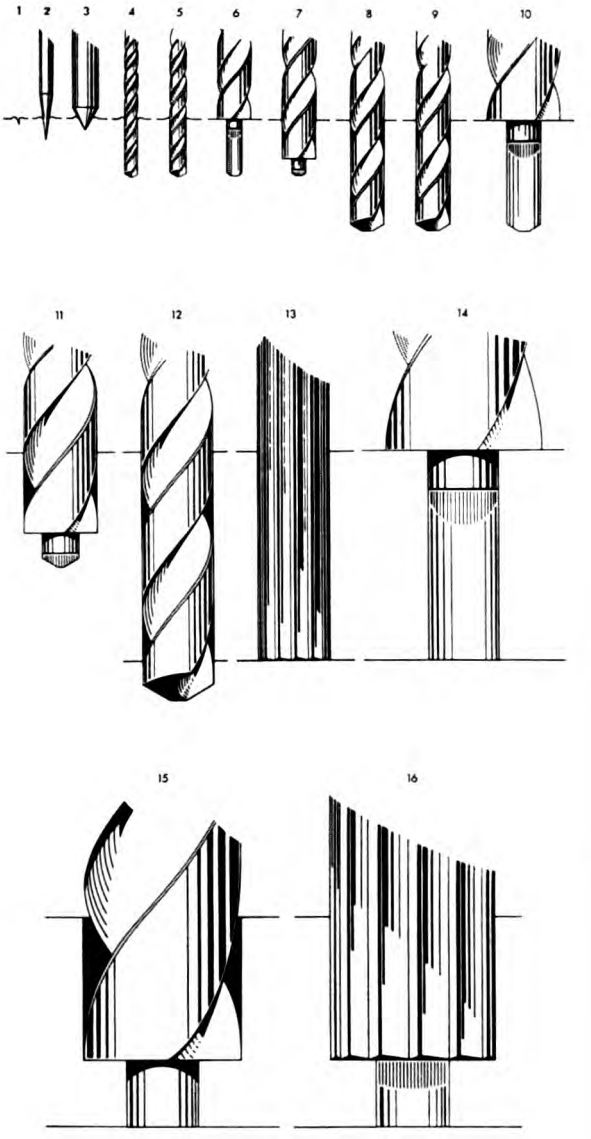
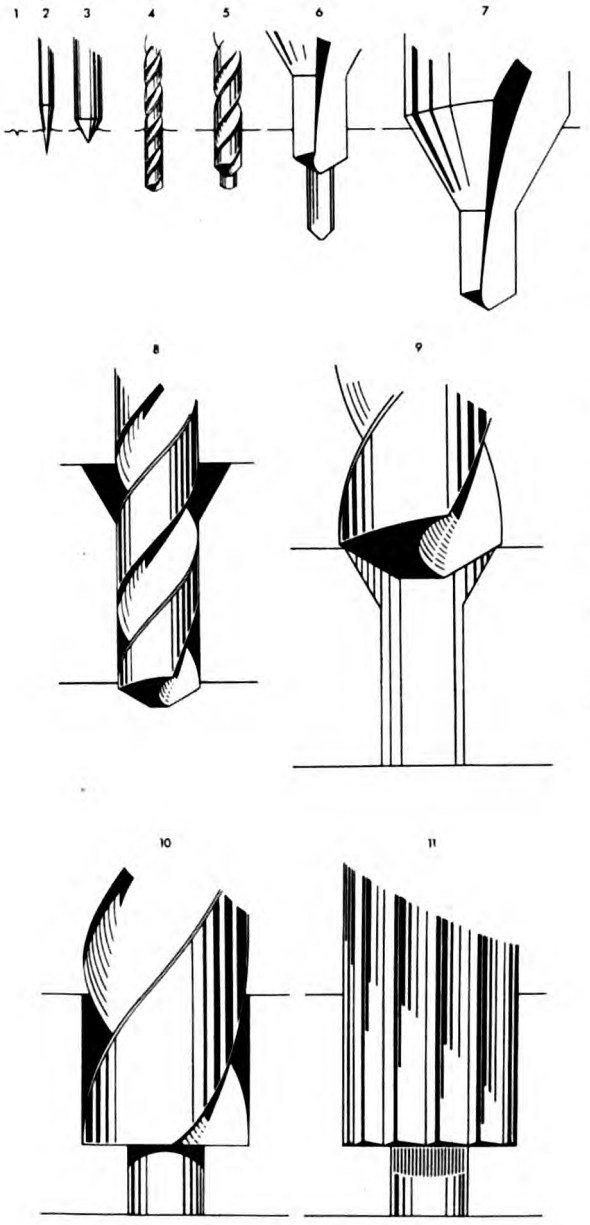


Fig. 25 — System of drilling and counterboring from a layout, used with variations and short-cuts by many toolmakers. A multiplicity of special tools is required. Once made, these tools may be used again and again.



1. *Scribed line*
2. *Rotating prick-punch*
3. *Regular prick-punch*
4. *1/32" drill*
5. *Approx. 3/32" drill*
6. *Center drill with 1/8" pilot*
7. *Same, deeper*
8. *Drill 1/4" through*
9. *Drill 23/64"*
10. *Drill 23/64" with drill ground to cut flat on end. This is to square up shoulder.*
11. *Finish ream hole to .375"*

Fig. 26 — A procedure simpler than that in Fig. 25 for drilling from a layout. Use of the center drill after the starting drill permits more flexibility with less special tools. However, some loss of accuracy results from the fact that drills do not follow conical holes as accurately as counterbores follow true cylindrical holes.

The die is stood up on its finished edges, and the heights of holes are compared in both directions. Either gage blocks or a height gage may be used. The indicator point may be applied directly to the surface of the hole or to close-fitting inserted plugs, Fig. 27. In either case, new computations are required, since half the diameter of the hole must be added to or subtracted from the center line of the hole.

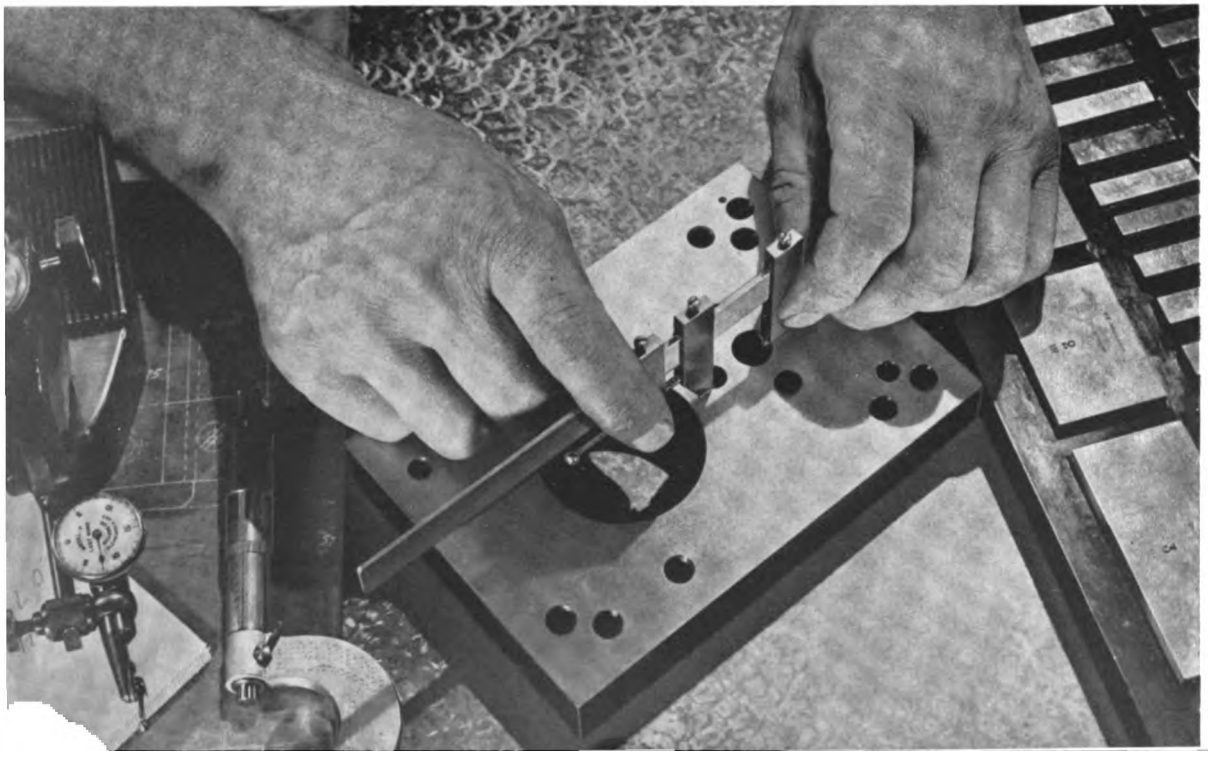
Fig. 27 — Procedure necessary for checking positions of holes after boring. New computations are required for this, since half the diameter of the hole must be added to the height of the center line of the hole.

The two largest holes were single-point bored; their positions are probably accurate enough. As a matter of fact, small errors here can do no harm. If the distance between them is incorrect, it affects only the stock feed through the die. If off sideways, the stock feed can be made parallel by grinding the sides of the die after hardening.

The relation of the four outside piercing holes to the center piercing hole is important, however. Since these holes are all pierced at one time, their interrelation is established at this point, and errors will remain in the finished blank. See Fig. 6.

More uncertain methods have been employed on the four outside piercing holes; therefore, there is some chance that these

Fig. 28 — Another method of inspecting for hole locations after boring employs vernier calipers. This method checks only the distance between any two holes and does not take into account angular displacements without measuring the chord between each pair of holes, in which case extensive trigonometric calculations are required.



contain errors. If not too large, they can go uncorrected; if outside the tolerances, they must be corrected. This is one of the things that makes the job laborious.

Corrections may be made by scraping or by single-point boring. Once the error is known, one side of the hole is scraped by hand until elongated by an amount twice the error, and re-reamed with an oversize reamer. An oversize plug must now be used for re-inspection of the hole, and an oversize bushing must be made for the die.

Another method of hole-correcting is by single-point boring. The die is set up on the lathe faceplate in such a manner that the indicator shows the hole to be eccentric in the same direction and amount as the known error. When bored, the location will be substantially correct.

Correcting to locational tolerances of ±.0001″ by this means is extremely tedious, because of the difficulty of maintaining good running conditions in the lathe spindle. Any looseness of the spindle makes the indicator give inconsistent readings; furthermore, it will not run, when boring, on the same axis as when indicating. Sometimes the toolmaker finds it impossible to get the last few "tenths" in this manner. He resorts to scraping anyway.

Since the original tolerance expected of this particular die was placed at ±.002″ or ±.003″, however, the correction is not too difficult. It is a nuisance which must be expected if we employ methods not certain to produce good results the first time.

Before hardening, the die should be carefully examined to make sure the required screw holes and dowel holes are drilled.

Locational errors are seldom improved during heat-treatment. The distortion usually makes them worse. In addition, bending or twisting of the die throws the axes of the holes out of parallel. Moreover, the heat required for the hardening decarburizes or roughens the surfaces of the die, shortening their life. The toolmaker knows these things, but the correction after hardening is such a slow and expensive job that, unless absolutely necessary, he avoids it. For some purposes, it is necessary, and methods for correcting locations will be discussed later.

For the present, however, we are still assuming that high accuracies in this die are not necessary; therefore, we shall accept the condition of the die as it comes from hardening.

Transferring — Although high accuracy in the final locations of the holes in the parts produced by this die is not necessary, the alignment between the die holes and the punches must be held close enough to produce a uniform "break". The holes will be *transferred* to the stripper and to the punch plate.

After hardening, the bushings are

pressed in. The top and bottom of the die are ground, the bushings being ground flush. Also, the edges of the die are ground parallel to the line of the two main holes to determine direction of stock feed. The stripper is now doweled to the die, and the holes transferred to it, Fig. 29.

Location is accomplished either by using the holes in the dies as guides for cutting spotters, drills and reamers, or by using them to guide special prick-punching spotters, which make prick-punch marks. In either case, special tools have to be made, since the holes in the dies are not standard sizes; their sizes depend upon the size of the hole desired in the piece part, and the clearance between the punch and die. In this particular case, the holes in the die bushings will be .131″. The nearest fractional size, 1/8″ is .006″ too small.

Fig. 29 — Transferring a hole from the hardened die to the stripper. Special tools must be made for this operation since the hole in the die bushing is not a standard size. Location is spotted with a .131″ spotter, the hole drilled through with a 1/8″ drill and reamed with a special .131″ reamer. Counterbore with .131″ pilot must be used to enlarge the hole to proper size for the stripper bushing.

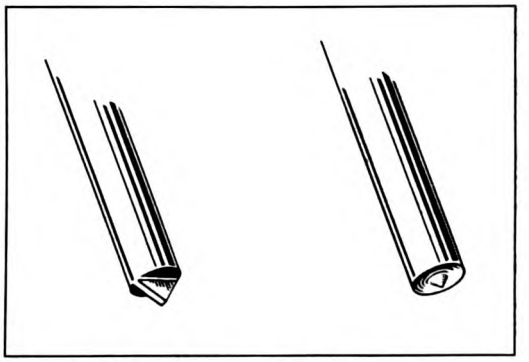


Fig. 30 — Typical spotters employed in transferring. The one on left is intended to be rotated in a drill press, and cuts a conical-shaped spot, to guide a drill. The one on right is intended to be struck lightly with a hammer. This makes a prick-punch mark, which can be "wiggled" up on the lathe faceplate.

If we elect to drill and ream the holes, a special cutting spotter .131″ must be made, Fig. 30, left, to drill a spot large enough to guide a 1/8″ drill. After the hole is drilled, it must be reamed with a special .131″ reamer, since it is important that the reamer fit its guide very closely. A counterbore with .131″ pilot must now be used to make a hole large enough for the stripper bushing.

If we elect to prick-punch spots for the holes, special prick-punching spotters .131″ diameter must be made, Fig. 30, right. These spotters make small prick-punch marks, which can be drilled and counterbored, or "wiggled up" on a lathe faceplate, and bored, as illustrated in Figs. 19 and 20.

GENERAL REMARKS ABOUT THE TRANSFERRING METHOD

Although we have not yet discussed all the transfer methods, we propose, at this point, to interrupt the discussion to consider grinding practices. Some of the transferring methods are employed in grinding holes to location. Grinding, therefore, should be discussed now as a prerequisite to some of our transferring practices. For further discussion of transferring see The Carrier Method for Progressive Dies, pages 38 to 40, and The Master Plate Method, pages 40 to 48.

Some of the disadvantages of the transfer method, *as employed up to this point*, will already be apparent to the reader:

1. It is a compromise, employed by the toolmaker to avoid working to know dimensions, and to avoid the tedious process for correcting hole location after hardening.

2. It precludes any possibility of making tool parts concurrently. The hardening distortion errors are carried through the stripper and punch plate to make these parts align. These parts, therefore, cannot be made until *after* the die is made and hardened. The delay from this in a simple die such as our present example is not serious. In a complicated multi-section die such as Fig. 211, however, it amounts to several months, a substantial part of the elapsed production time.

3. Although grinding of holes is *not necessarily* omitted when transferring is employed, it usually is omitted, as a part of the compromise. Decarburization, therefore, is usually retained, to the detriment of cutting edges.

4. Tool parts are not readily replaced. Since the original parts contain errors, any new parts must have these same errors. Replacement parts, therefore, cannot be made to known dimensions. They also must be made by transfer.

In all fairness to the toolmaker, it should be pointed out that he has little choice in the matter. As shown in Chapter I, he is forced by cost limitations and the lack of equipment to get the job done the best way he can.

Grinding — The die we have taken as an example up to now has been assumed to have rather loose requirements. We have allowed errors of $\pm .002''$ to $\pm .003''$ in the location of the holes, and have accepted the die in its unground condition after hardening. The die can be considered finished, and it will work satisfactorily, provided we accept the locational errors and are satisfied with the comparatively short runs which a die with unground holes will give.

We shall now reverse our original assumption and analyze the process of producing a die with high accuracies. For this purpose we shall consider a die similar in all respects to our previous example, except that it will cut thin stock, and loca-

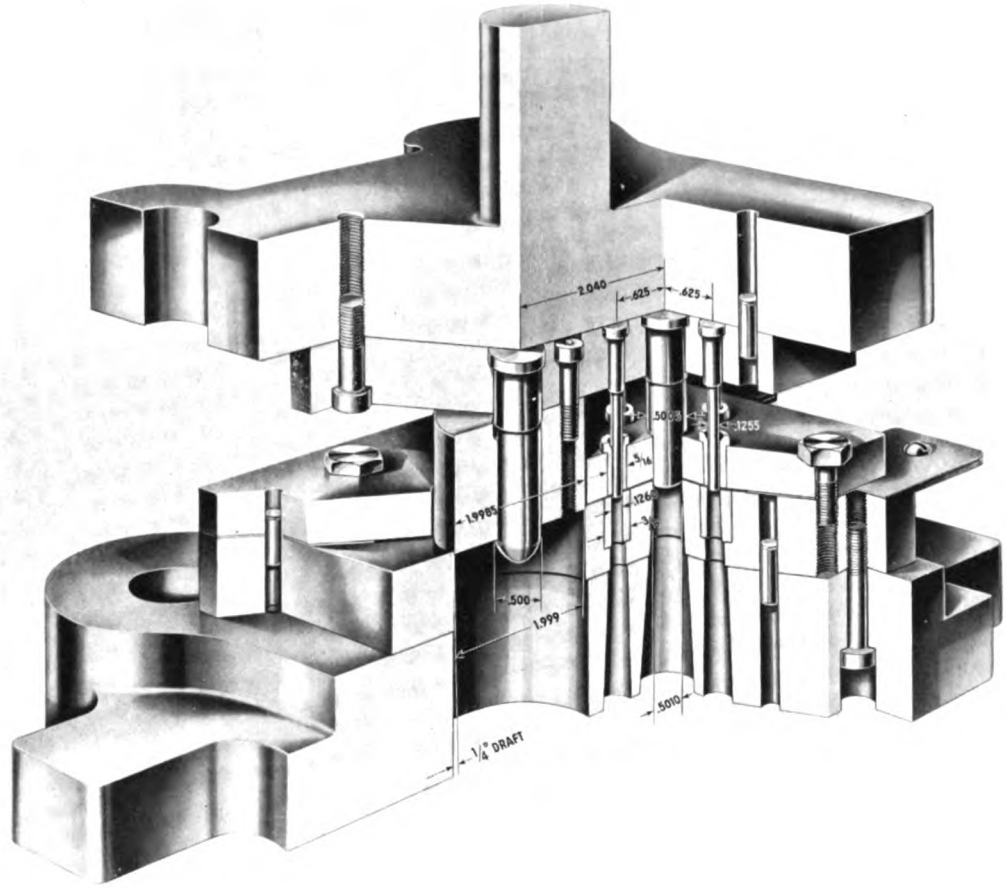


Fig. 31 — Dimensional details of die required for piece part in Fig. 32, made from thin stock, and held to extremely close tolerances. This necessitates more accurate alignment and harder, sharper cutting edges. The only way to build long life into this die is by grinding all parts after hardening, including all holes.

tional tolerances in the piece part are reduced to .0005″ instead of .003″. Dimensional details of die and piece part, Figs. 31 and 32, are substantially different from those originally assumed, Figs. 6 and 7. We cannot now accept the distortion errors or decarburization from heat-treating; all holes must be ground to size and location.

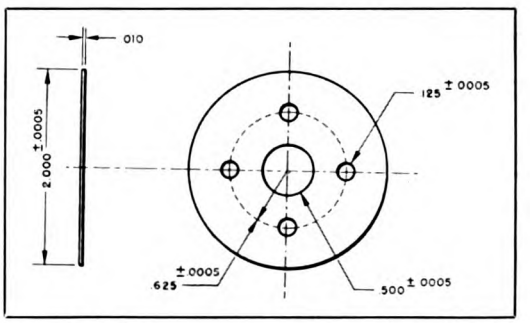


Fig. 32 — Piece part to be made from die in Fig. 31. Thinner stock (and, therefore, smaller die clearance) and tightening of dimensional tolerances render this job far more difficult than that in Figs. 6 and 7. Extreme care must be used in building the die.

Up to the point of heat-treatment, the

work progresses the same as if we were not planning to grind, except that .010″ to .015″ of stock must be left in every hole to grind out after hardening. The locations of the holes should be established by some reasonably accurate means; otherwise an excessive amount must be left for grinding to be sure the holes will clean up to size in their correct locations.

After hardening and after grinding the top and bottom of the die, but before grinding any of the holes, we must consider which dimensions must be held, and which need not be held, to achieve satisfactory performance without spending unnecessary time. Inasmuch as this die contains only two stations, it is not necessary that distance 2.040″, between the blanking and the main piercing holes, be held accurately. This distance affects only the amount of scrap, and a thousandth or two here is not worth considering. Therefore, we shall grind these two holes in their present positions, by indicating each on the lathe faceplate and grinding to size and with the correct taper or draft, Figs. 33 and 34. (Note here that this is permissible only in a two-station die. If this were a multi-station die, such as shown in Fig. 211 or 304, this could not be done. In multi-station dies it is imperative that the move between all stations be exactly alike, and, therefore, must be correct.)

After the two main holes are ground, the edges of the die are ground parallel to

Fig. 33 — Setting die block on faceplate preparatory to grinding blanking hole. Awkwardness of holding die, straps, and bolts necessitates removal of faceplate from machine.

their center line. The ends are now ground perpendicular to these edges. The edges and ends must be done carefully; they

Fig. 34 — Grinding main blanking hole in die block. Die has now been heat-treated and accurately ground all over. Main holes will be used as references from which other holes are established.

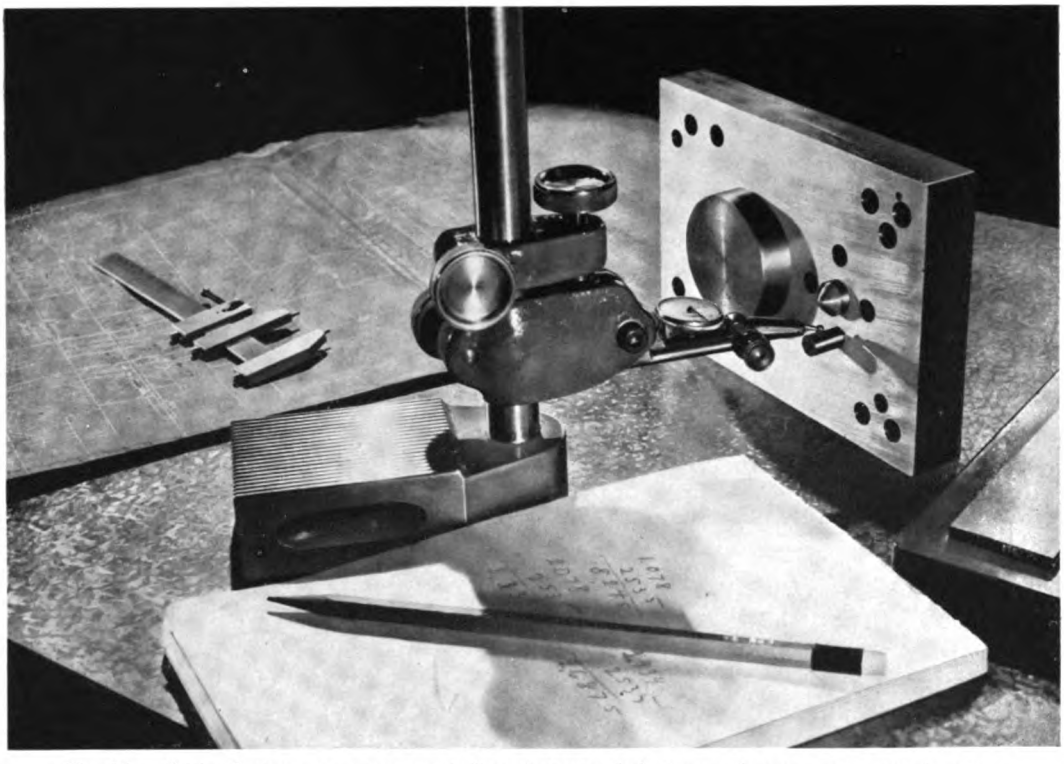


Fig. 35 — Setting button preparatory to grinding of piercing hole. Inasmuch as extreme accuracies are required, a height gage is not considered sufficiently accurate. Dimensions should be compared against stacks of gage blocks. Buttons are individually indicated on lathe faceplate and removed before grinding holes.

should be correct within .0001″, because they are to be used as working edges for buttoning the four outside piercing holes in close relationship to the center piercing hole.

Because of the close dimensional accuracies now required, a height gage is not sufficiently accurate; settings should be compared with stacks of gage blocks, Fig. 35. Dimensions must all be re-figured. Since the edges of the die have been ground, they will be different from those used in setting the buttons before hardening. There is now no place for a tapped hole, so bolts must be long enough to extend clear through, Fig. 36. Sometimes,

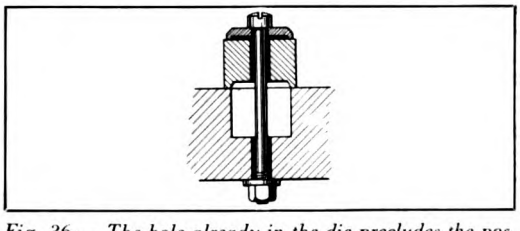


Fig. 36 — The hole already in the die precludes the possibility of a tapped hole to hold the button; a bolt long enough to extend through the die avoids this difficulty.

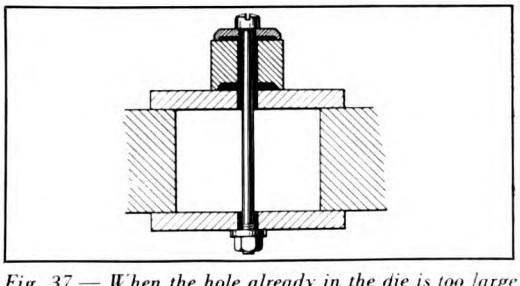


Fig. 37 — When the hole already in the die is too large to support the button, false steel plates are employed. These plates have considerable inertia, and there is great danger of disturbing their positions when rapping the die around on the faceplate to true it up.

when re-buttoning holes too large to support the button, steel plates are laid over the holes, Fig. 37.

Since we are now working to "tenths", it is imperative that accurate tools be used. and that all operations be done with a maximum of care and attention. Setting the buttons is no small job in itself, a fact which will be confirmed by any experienced toolmaker. After the buttons are set, the die block is swung up again, either on the faceplate of a lathe, and ground with a grinding attachment, or on the faceplate of a regular internal grinder. This is a more delicate job than the setting of the buttons, because of the difficulty of getting the work spindle to operate correctly. The spindle must be perfectly round, and the bearings must be set up so tight that all end play and side play are taken out. Spindles set up tightly enough for this soon wear and loosen up, and the machine needs almost constant tinkering to keep it operating successfully. Counterweights must be applied to prevent misalignment from centrifugal forces, in case the work does not balance, Fig. 34.

Checking the holes after grinding is even more tedious than setting the buttons. Inspectors not aware of the many chances for error often find errors which do not exist, or pass real errors. True plugs must exactly fit the holes, to prevent them from tipping and giving false readings. All readings should be taken at some point on the plug as near the surface of the die as possible. Out-of-roundness is especially difficult to detect. Angle irons should be checked carefully for perpendicularity. Care should be exercised even in the clamping of the work to the angle iron, lest excessive pressures distort the workpiece. All computations for height must again be re-figured, since grinding has changed the hole sizes.

At this point even the experienced tool and gage maker is amazed that the holes are not located where he expected to find them, because of the many chances for error, all of which conspire against him:

1. Difficulty of setting buttons preparatory to grinding, Figs. 22 and 35. This is an exasperating detail, since there is no way to move the button a pre-determined amount except to rap it with the hammer, and check it with the indicator in *both* directions after each blow.

2. Lack of rigidity of all the equipment used in the process. When working to "tenths", either in making tools or in the building and checking of machine tools, the mechanic soon learns that steel and cast iron are not fixed, solid things, but that they act more like pieces of rubber screwed together, bending and warping at the slightest pressure.

3. Lack of proper design of equipment to eliminate as much "spring" as possible. Surface gages, for instance, are usually far too springy. The spring in lathe spindles

is easily observed when trying to indicate the button. In addition, especially in plain-bearing spindles, the necessary oil film changes the position of the axis of rotation when the spindle revolves under power, the net results of which are inconsistent indicator readings, and the fact that the hole is not ground in exactly the same position as the button.

4. Lack of full knowledge on the part of the toolmaker just where the allowances should be made. This is not to disparage the operator's skill, since the equipment available is usually a poor foundation upon which to build high precision. But, to make any time on the job, the toolmaker has to do a certain amount of gambling, and he takes the chance that, even by working rapidly, he will not be off by an excessive amount. So, he averages up the inconsistencies he finds in indicator readings, makes a quick guess at the amount of counterbalancing he needs, and goes ahead. It is not surprising that, when he comes to the checking, he finds errors. Indeed, considering the conditions, it is a tribute to his skill that he finds so few.

Errors found are usually corrected by indicating on the faceplate, allowing for the errors, and re-grinding, continuing the process until they all check correctly against gage blocks on the surface plate.

Assuming that the die is accurately made, the holes in the stripper and the punch plate must also be accurate. The stripper and punch plate, if anything, must be *more* accurate than the die, since the point at which the punch enters the blank is the main controlling factor in the location of the hole in the finished piece part. The job of transferring the location from the die to the stripper and punch plates, therefore, is of extreme importance. Often, regardless of the care put into this part of the job, small errors creep in, and the toolmaker makes adjustments in his own way, by scraping the stripper holes, bending punches, or some other makeshift method.

A reasonable amount of care in the manufacture of a die by grinding produces results infinitely superior to that of an unground die, both from a standpoint of accuracy of the piece part and of die life, two factors of great importance in high-production items. Dies produced in this manner are usually expensive, but the additional cost is justified by the enormous increase in production.

Experience indicates that production between grinds may be increased as much as 1000%.

The Carrier Method for Progressive Dies — Progressive dies for making odd-shaped blanks present a unique problem. The usual practice is to make an accurate template, containing correctly located holes, and use this template as a pattern for the blanking hole in the die. The draft in the die permits the template to be inserted from the back, and "shuts out light" when the template is brought to the top of the die.

For economy of scrap, or to avoid rupturing blanks subsequently bent in forming dies, the blanking hole is frequently laid out at some odd angle on the die, Fig. 38. Even in cases where the blank is *not intentionally* laid out at an odd angle, the template does not come out exactly in the same position as the original layout when it is brought up by filing the die. In this simple, two-station die, this is of no consequence, so long as the piercing holes, when subsequently laid out, bear the correct relationship to each other and to the blank holes.

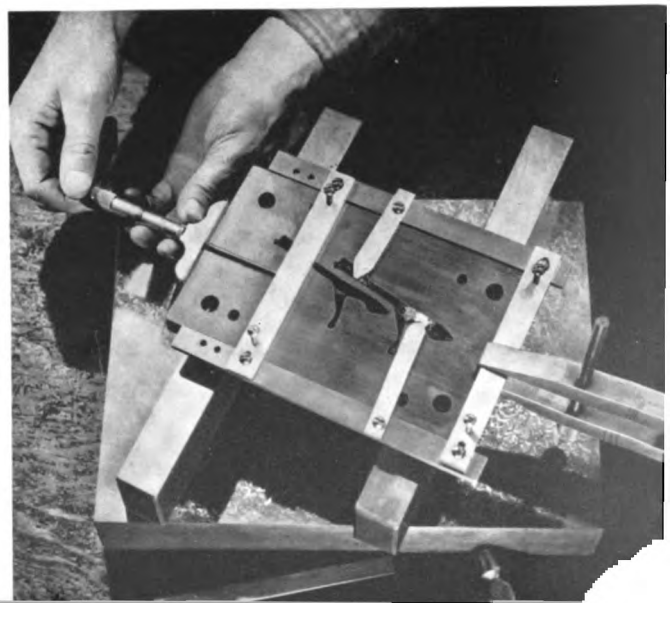
Fig. 38 — Inserting template into blanking hole preparatory to transferring piercing holes with carrier, an ingenious, although commonly used, method for insuring good parallelism of stock travel and correct orientation of piercing holes with blank hole. Holes are already transferred into this die; photos merely illustrate principle.

To bring this about, a carrier is used, Figs. 39 and 40. Two steel rails, held together by adjustable clamps, straddle the die. Arms attached to the rails are then soldered to the template, as shown. The template, still attached to the carrier, is now lifted out of the blanking hole, carried along a distance equal to the stock move, and clamped on the die. Holes are now transferred through the template into the die. The holes will, therefore, bear the correct relation to each other, and, since the template is kept parallel to the blank hole by means of the carrier, they will be correctly oriented.

The carrier method is used for economy in the making of the tool; it has serious

Fig. 39 — Fitting carrier to die. The two steel rails must be adjusted with the cross clamps so the rails exactly fit the die, to insure a parallel transfer and enable stock to travel parallel with edges of die.

Fig. 40 — In a two-station die such as this, the move can be measured accurately enough with a depth-gage. For more than one move, this measurement must be made with extreme care.



limitations for some kinds of work:

1. It does not readily produce results with high accuracies. The carrier parts are light, and, therefore, springy. The toolmaker does not, therefore, have 100% assurance that it will locate the template exactly as it should. It is also limited by errors common to all transfer methods, page 33.

2. It does not readily adapt itself to correcting location by grinding. To grind holes, it would be necessary to remove and replace the carrier each time a hole is picked up, a very tedious process. This method, therefore, is not ordinarily employed for this purpose.

3. It is not suitable for multi-station dies. Dies with more than one stock move must be very accurate, to insure good stock feeding. Moreover, multi-station dies are frequently made in several sections, and cannot be finally correlated until all sections are hardened and fitted together in the die holder.

Master Plates—The Master Plate Method is largely a system of transfer, and may appear to be a repetition of transfer methods previously described. A description of its principles and an analysis of the reasons for its development, however, show it to be substantially different from previously discussed transfer principles. Since it has been widely used in watch and clock factories in Switzerland and this country for at least one hundred years, this process should be noted carefully as an important milestone in the history of the toolmaker's hole location problem.

Firearms, clocks, and watches were among the first mechanical devices built in large quantities. To produce them economically, the parts had to be made interchangeably and a way found to reproduce hole location. This was an early step toward mass-production practices. Since the master plate method includes the swinging of master plate and tool parts together on the lathe faceplate, it is not suitable for large-sized work. It is best adapted, therefore, and most widely used in watch and clock factories, where most of the tools produce small parts.

It must be remembered that, one hundred years ago, no accurate standard of measurement, such as Johanssen Gage Blocks, was available. Therefore, whatever reproductive method might be employed, it could not be built upon a firm foundation of dimensional accuracy. Nor were the parts interchangeable, in the *modern* sense of the word, to definite dimensions and tolerances. They were interchangeable in the sense that they were all duplicates of a working model.

Not only is the master plate method different from other transfer methods, but there are variations in the master plate method itself, as used in different plants. To explain this, two different examples will be shown, one now obsolete, formerly

used by the Seth Thomas Clock Company, of Thomaston, Conn., and the other, a modernized version, still employed by the Waltham Watch Company, of Waltham, Massachusetts.

The present status of both these situations makes an interesting sidelight on the progress of the hole locating job. Seth Thomas, being a clock shop, makes much larger tools and parts than Waltham. It is noteworthy that Seth Thomas, therefore, has discarded the master plate practice entirely in favor of the Jig Borer, whereas Waltham, not subject to the disadvantage of swinging heavy parts in a lathe, has retained the master plate principle, but employs a Jig Borer and coordinate checking machine in the making of the master plate. Both companies, heading in the same general direction, now work to *known dimensions* by coordinate location, but attain results through different processes. (For further discussion of coordinate location, see pages 120 to 125.)

The original master plate practices formerly employed by Seth Thomas are typical and will be described first. Illustrations are photographs of the *actual* master plate and dies for the *last* clock movement tooled at Seth Thomas by these practices.

The process starts with the building of the model. No engineering, in the modern sense, is done before the model maker starts. A few general instructions as to overall size and type of clock are given. The model maker is a real clock maker, and makes, from these general instructions, a working model of the proposed clock.

Holes in the various parts of the model are laid out and drilled in such positions as are required to make the clock run. The locations of the holes are not considered particularly important, so long as all the plates in the clock agree with one another. Some attempt is made, of course, to hold gear train holes approximately correct, but if errors occur here, they are compensated by making the gears oversize or undersize to suit. Since practically no standardization of clock gears existed, this practice was not objectionable. The introduction of the Jig Borer has subsequently permitted standardization of these parts.

Fig. 41 — Transferring hole location from clock model to master plate with wiggler. After the model is completed, it is taken apart, and holes from each part are transferred to the master plate. The model is pinned to the master plate through pillar holes, and is removed from the master plate after each hole is trued, before boring.

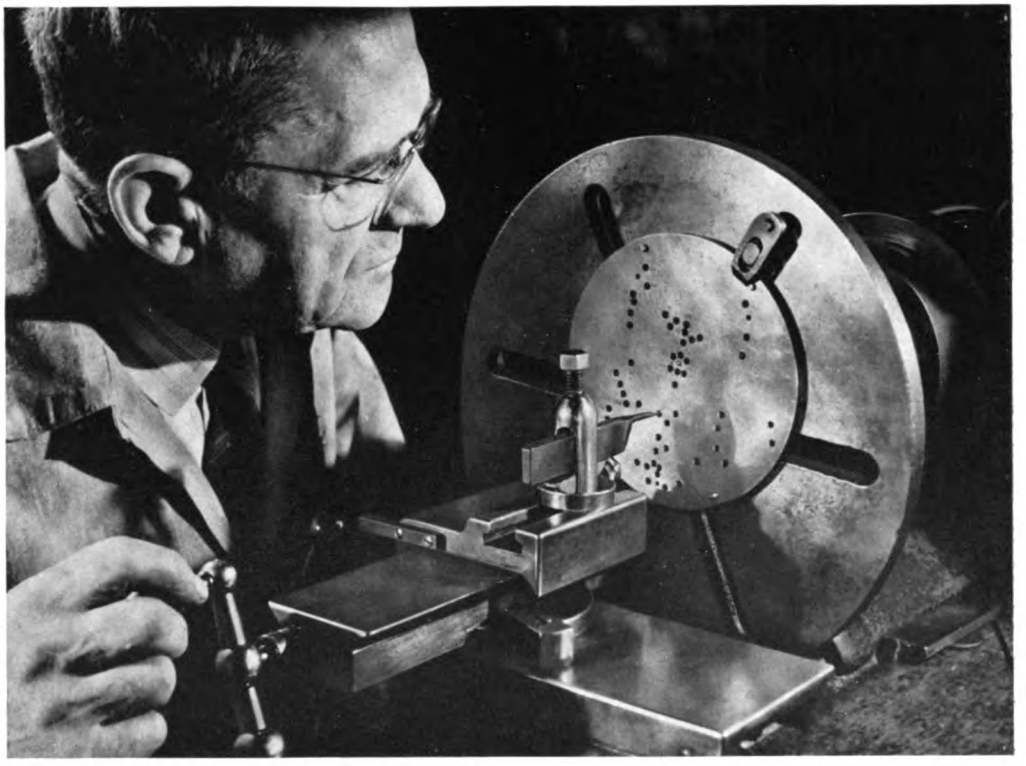


Fig. 42 — Boring hole in master plate after model has been "wiggled up" and removed. When master plate is finished, it will be used as references for positions of all holes in tools to make finished parts for clock.

After the making and approval of the clock model, the holes from all the plates in the clock are transferred to a single plate, called a master plate, Figs. 41 and 42. All holes in the master plate are the same size, if possible. Once this master plate is made, it is used as a reference from which *all* the holes in all dies, or jigs are transferred. Since they are all transferred from the same master, all holes in whatever plate they may be bear the correct relationship to each other. Pivot bearings will line up because, although made in two separate plates, they and the pillar holes are transferred from the same master. The master plate is usually kept in a vault and is closely guarded, since there is nothing else from which to duplicate the hole locations in new dies or jigs.

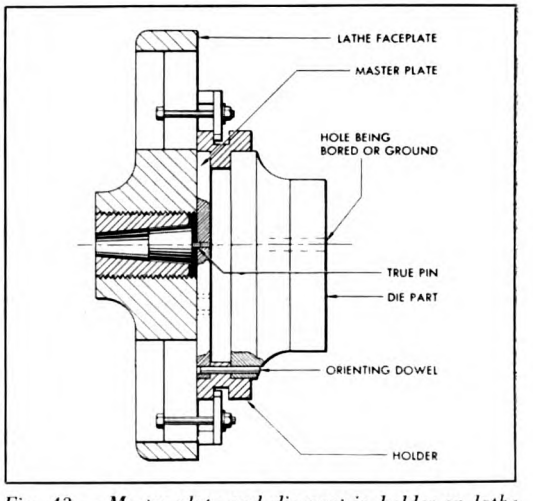


Fig. 43 — Master plate and die part in holder on lathe faceplate, ready for boring or grinding.

Fig. 44 — Setting master plate holder and die part on lathe faceplate preparatory to boring hole in die part. Location of each hole in die part is determined by slipping hole in master plate over true pin in lathe spindle.

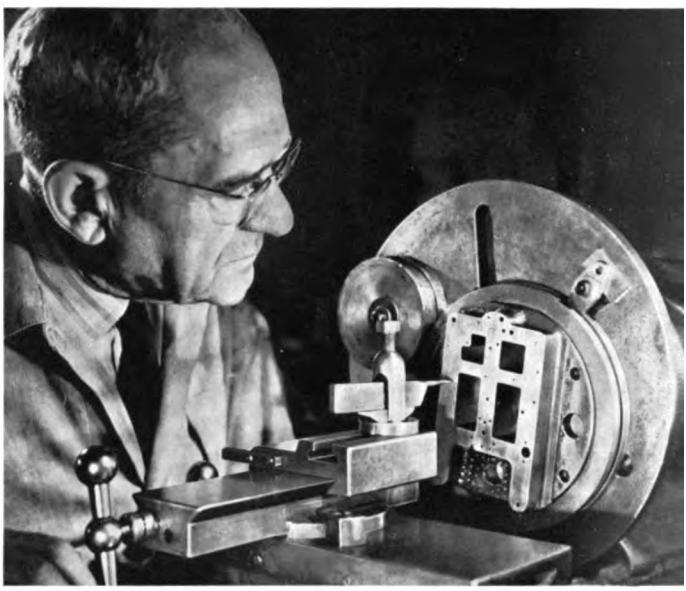


Fig. 45 — Boring hole in die part attached to master plate on lathe faceplate. Counterweight prevents centrifugal effect, caused by eccentric rotation of this heavy mass, from springing spindle and altering location.

To transfer the holes from the master plate to the die or tool part, both are mounted in a special holder, Fig. 43. Both sides of the holder are bored to fit their respective parts tightly, and the die further held into the holder with solder, Fig. 45. During the boring of any group of holes, they are not taken apart. This minimizes any possible dislocation between the master plate and die.

A pin protruding from the lathe faceplate is turned true and to the size of the holes in the master plate. The master plate is now attached to the faceplate with the pin in one of the holes, Fig. 44. The corresponding hole in the die or jig is now single-point bored, Fig. 45. All holes are done in the same manner. Since the pin is turned concentric, each hole bored is concentric with its corresponding master plate hole and the relative positions of the holes in any group is like the master plate within the limitations of the method.

The master plate method also adapts itself to grinding. After hardening, the die is again attached to the master plate and holder. To orient it to its proper position on the master plate, a pin is inserted into an extra hole in the master plate, holder and die part, Fig. 43.

Each hole is successively placed over a true pin in the lathe or internal grinder spindle, and the holes in the die ground. Regular grinding wheels or mounted points may be used for this if the holes are large enough. In holes smaller than 3⁄16″, diamond dust is used as the grinding medium, hammered or "charged" into mandrels

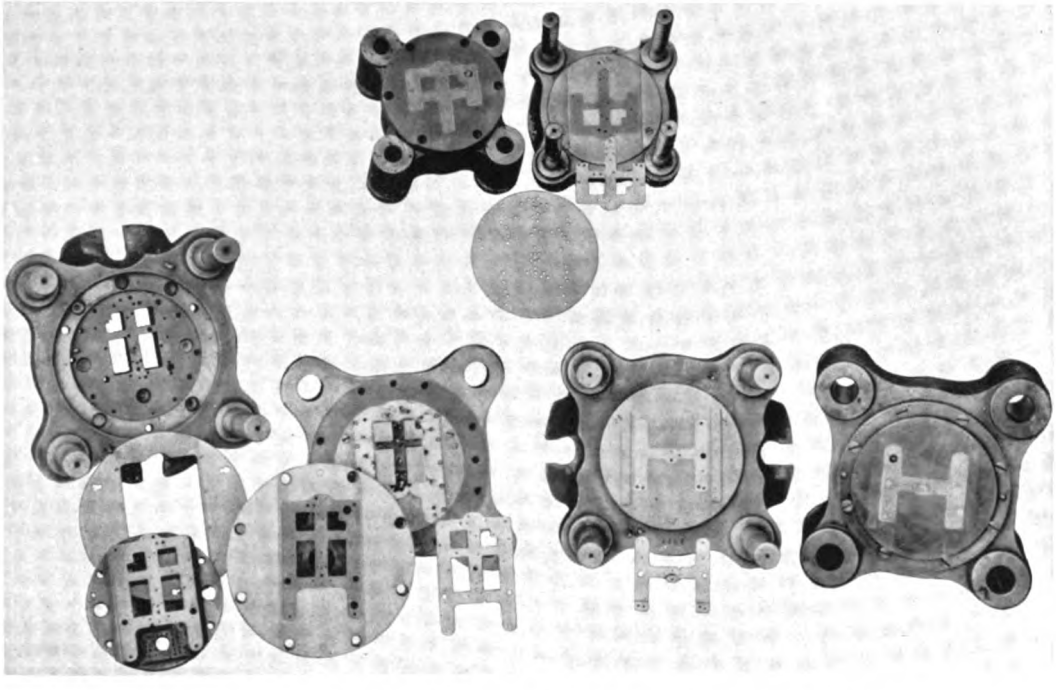


Fig. 46 — Master plate (center) and complete set of dies for producing clock parts.

made for the purpose. See Figs. 235 to 247 for complete description.

Fig. 46 shows tools required for the major parts of a clock, and the master plate from which they were made.

There are notable differences between the obsolete method described above and the modernized master plate procedure now employed at Waltham Watch Company. Chief among these is the fact that all dimensions are engineered, and the model made strictly to dimensions. The introduction of the modern Jig Borer and coordinate checking machine permit this. In fact, dimensions are regularly sent to the toolroom in *rectangular coordinate form*, for easy transposition to these machines.

Tool parts are, therefore, made to pre-engineered dimensions and tolerances. This is an important step, since it permits not only interchangeable assembly of plates and similar parts containing bearing holes, but also standardization of gears, escapements, and other parts among many styles of watches and instruments.

After engineering, a model watch is made, for test and approval, before making the master plate.

In the making of the master plate, parts of this model are not employed as templates for the transfer of holes, however. It is made independently to dimensions. The procedure is somewhat different from that formerly employed by Seth Thomas.

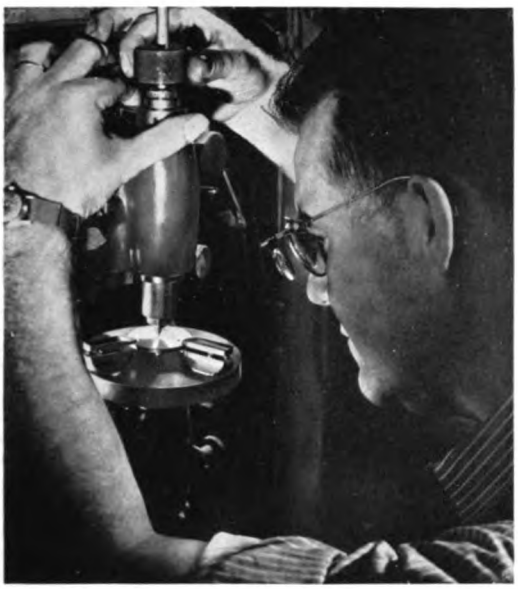


Fig. 47 — Figs. 47 to 54 illustrate the master plate practice employed by Waltham Watch Company, of Waltham, Mass. In this practice locations of all holes in master plate are pre-calculated to rectangular dimensions. A "prick plate" is made as shown, from which locations are transferred to the master plate. Locations of positions in the "prick plate" are determined in this Jig Borer.

Fig. 48 — Indicating prick plate attached to master plate preparatory to boring of master plate. Master plate is rapped back and forth on lathe faceplate until prick-punch mark runs true. The three holes shown in the prick plate are construction holes and play no part in the operation of the watch. They are employed to orient the master plate with respect to the various dies and jigs.

The first step is the making of a "prick plate", or prick-punched plate, Fig. 47. Small prick-punch marks are laid out with a Jig Borer on the surface of this plate. In addition, three widely-spaced construction holes (visible in picture), are drilled through the plate. These three holes bear no relation to any part of the finished watch; they are used to orient the prick plate to the master plate, and, transferred to the master plate, to orient it, in turn, to the tool parts. Since it would thereby be distorted and its prick-punched surface ruined, the prick plate is not hardened.

The master plate blank having been turned up, and its faces ground, it is now attached to a holder preparatory to boring. The first holes put in are the three construction holes. Pins are inserted, fitting both the prick plate and the soft master plate accurately. The prick plate may now be attached to or removed from the master plate at will, without fear of losing location. One after another, the prick-punch marks are indicated, Fig. 48, the prick plate removed, and the holes bored in the master plate, Fig. 49.

Fig. 49 — Drilling and boring master plate.

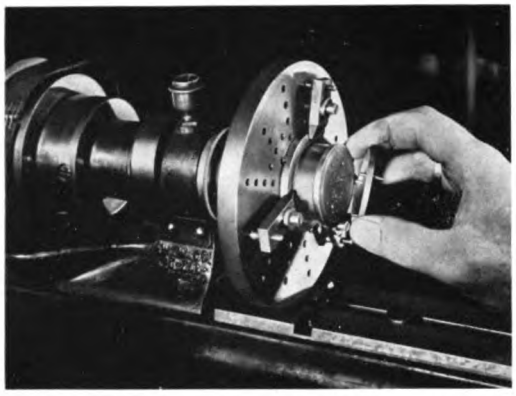


Fig. 50 — After hardening of master plate, prick plate is again plugged to master plate through three construction holes. After re-indicating prick plate, hole in master plate is ground to correct distortion from heat treatment.

After boring, the master plate is hardened. The first holes to be ground are the three construction holes. To accomplish this, three plugs are made up, just loose enough in the holes to permit them to be plugged through. This looseness is necessary because of the hardening distortion. If the looseness is uniform between the three holes, the prick plate will automatically orient itself to approximately the average position of all the holes in the hardened master plate. One after another the part of the pins protruding from the front of the prick plate are indicated, and the corresponding hole in the master plate ground. After grinding each of these holes, a new pin is made to fit both it and the prick plate. The prick plate may now be attached to or removed from the hardened master plate at will, Fig. 50, and each working hole indicated and ground, usually with diamond-charged mandrels.

The reason for making the prick plate is now evident. It is used twice — once for boring and once for grinding. Without it, there would be no reference points from which to grind the holes after hardening.

The master plate is not considered sufficiently accurate until it is carefully checked, however. For this purpose a high precision Zeiss coordinate checking machine is employed, Fig. 51. Errors are meticulously tabulated, and the master plate returned to the toolroom for correction.

Errors are frequently found at this point, produced from many causes. The prick-punch originally employed does not locate the prick-punch mark exactly, the pump center does not pick it up exactly, and the spring of all parts of the equipment precludes 100% sensitivity of the method.

These errors are easily corrected, how-

Fig. 51 — After grinding all holes, master plate is carefully checked in high-precision toolmaker's microscope. It is not necessary to maintain accurate sizes of holes in master plate. See Fig. 52.

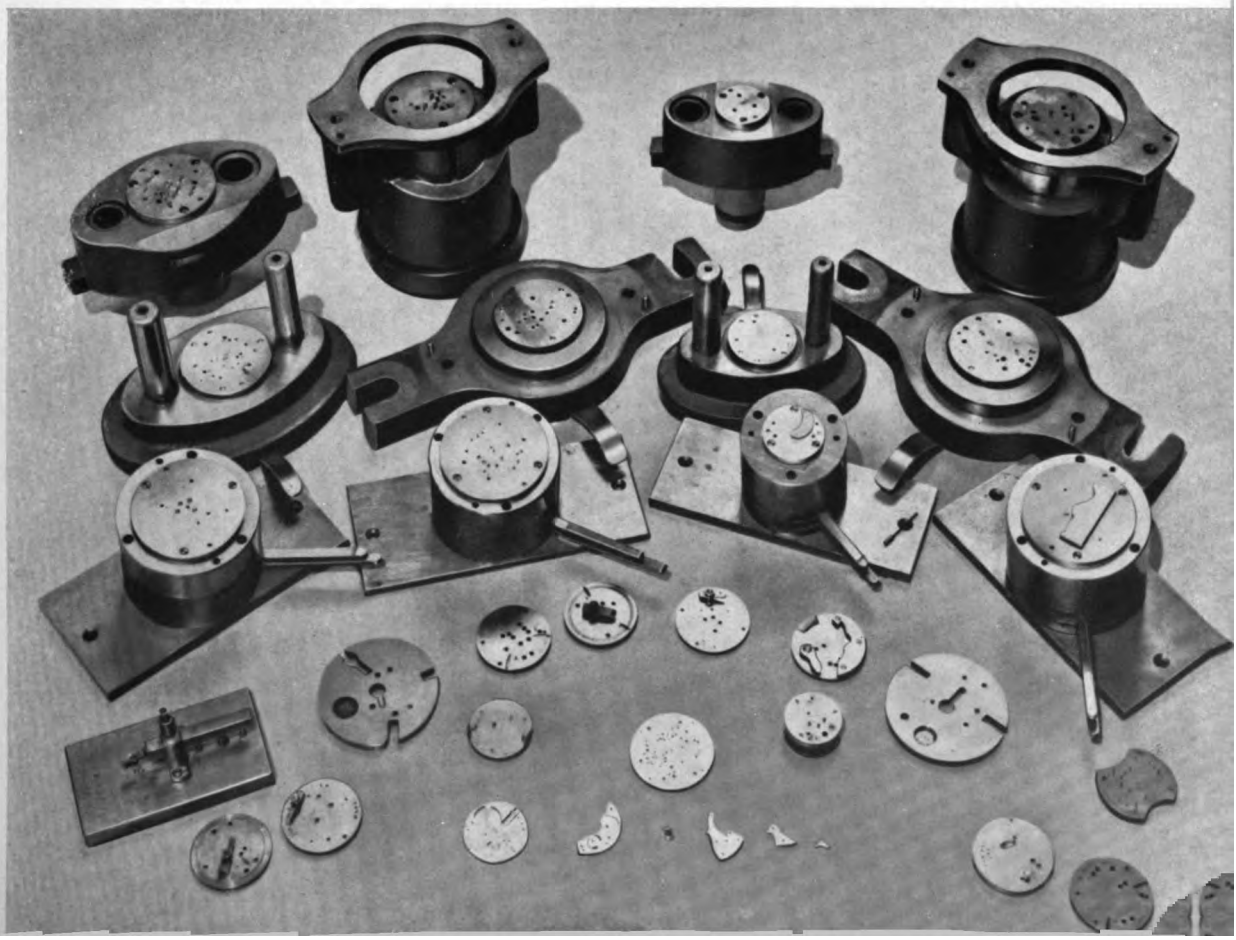
Fig. 52 — Indicating master plate mounted on die part. Note, since the inside surface of the hole is indicated instead of being mounted on a pin, it is not necessary to maintain accurate hole sizes in master plate.

Fig. 53 — Master plate removed from die part, hole in die part is now ground to correct location, usually with a diamond-charged mandrel. For description of this procedure see Figs. 235 to 247.

ever, by indicating directly in the hole, and throwing it off an amount equal to the charted error, and re-grinding.

Holes can be ground for correction as many times as necessary, since they do not have to be held to size, to fit a pin, as in Fig. 44. Instead, the hole is indicated directly, Fig. 52.

Fig. 54 — Group of dies, jigs, and fixtures for complete set of watch parts made from master plate. Wherever possible all holes in all parts are put into the same master plate. Occasionally, holes come so close together it is impossible to put them in the same plate. In such cases several master plates might be made for the same watch.



After correction, the master plate is used to transfer all the holes to the tools. It is plugged to the tool through the three construction holes, to insure perfect relationship between the holes in all parts of the watch. Holes in all tools, after hardening, are usually finished by diamond grinding, Fig. 53.

Watch and clock making, from the model and master plate to the finished tools, is a laborious hole locating process. The two different master plate systems described not only illustrate this, but also serve to prove the point previously mentioned, that, until recently, very little progress has been made in hole location as compared with other parts of the toolmaker's job.

At this point, a few observations regarding the master plate principle are in order:

1. Although successfully used for many years, its original form was in reality an evasion, developed to fill the gap caused by the lack both of standards of measurement and position measuring equipment. This does not in any way disparage the ingenuity of the master plate idea. Standards of measurement simply did not exist, yet the demand for manufactured goods forced the manufacturers into the application of whatever means was nearest at hand to produce parts on an interchangeable basis.

2. Its value drops rapidly as the size of parts increase. The larger the part, the larger and more cumbersome the machine. Boring small holes in large parts in big, heavy, slow machines is extremely inefficient.

3. It is not satisfactory for box jigs or tools containing holes in many directions, for the same reason as in **2**. Large overhang, heavy weight, and the difficulty of applying counterweights make conditions worse.

4. It must be used carefully to attain high accuracies. Construction hole pins must fit very closely, to insure accurate duplication of position. Clamping creates distortion. Holes and pins become nicked or worn.

5. It does not adapt itself readily to a quick tooling-up program. As many as thirty or forty dies, jigs, or gages may be required for a single clock or watch frame. Since only one master plate exists, the hole locating job can be done on only one tool at a time. This is liable to spread the tooling over a several-month period.

6. In its original concept, the actual dimensional locations of the holes in the master plate are not known, and cannot be recorded on drawings. The master plate, therefore, must never be lost or damaged.

7. Separate layouts must be made whenever it is necessary to relate the holes to *edges* of the workpiece.

8. Recent trends in its form of application show the desirability of positive dimensional locations, in place of the transferring of location from one part to another; also the desirability of *engineered equipment* to solve the hole locating problem, employing the modern coordinate location system.

The Coordinate Location Principle — It is reasonable to expect that a way should be sought to overcome the difficulties encountered when locating holes by layout, buttoning, transferring, or master plates. The coordinate location principle is the natural solution.

In some cases the location of one or a group of holes must bear an accurate dimensional relationship to the edges of the die or jig part. In other cases it is merely necessary that the holes be accurately spaced from one another. An example of this is the die shown in Fig. 5, and subsequently described. While the holes must bear an accurate relationship to each other, it is not essential that they be in any particular place in the die. The only reason for accurately squaring the die block was to establish base surfaces for layout purposes. Considerable unnecessary work was done in squaring up and laying out from the edges, instead of relating the holes directly to each other in the first place.

The master plate accomplishes the interrelationship of a group of holes, but does not easily relate holes to edges.

None of the methods heretofore described is fully efficient for *both* conditions. Toolmakers sought, therefore, a method for performing the locational operation by moving the workpiece with respect to the tool, or vice versa, making definite dimensional measurements by some extraneous means.

Inasmuch as single-point boring and grinding are the most accurate cutting methods, it is natural that measuring devices were first added to machines already used for these operations — milling machines, lathes, and internal grinders.

Fig. 55 — Milling machines equipped with measuring devices (on front of machine, not visible) for boring holes in pieces too large to swing on lathe faceplate. Inconvenient for operator; not suitable for high accuracies.

The milling machine provides the largest travel, and, since the work does not revolve, it is capable of boring large, flat pieces, also built-up jigs and fixtures.

A variety of measuring devices can be employed, such as scales, micrometer heads, gage blocks, and indicators. The chief disadvantages of these methods are:

1. Milling machines are not customarily designed or constructed with a view toward high accuracy.

2. Direction of approach is extremely inconvenient for operator, Fig. 55. This is improved, of course, by using vertical milling machines, but the knee-type construction precludes any possibility of high accuracy.

Lathes and internal grinders are also equipped with crude measuring devices, Fig. 56. A right angle guide is attached to the faceplate, and moves made with respect to it with gage blocks. Chief disadvantages:

1. Lathe spindle not usually accurate enough to maintain high precision.

Fig. 56 — This method shows another possibility for grinding the die piercing holes in the die block in Fig. 34. Center piercing hole is indicated before attaching square. Gage blocks determine correct setting for square. To move die block to correct locations for other holes, gage blocks are added or subtracted.

2. Inconvenient to operator; great care must be employed when handling the gage blocks and when clamping.

3. Not suitable for large pieces. Since the whole mass rotates, careful counterbalancing is required.

The inconvenience, inaccuracy, and obvious size limitations of the milling machine and lathe or internal grinder fixtures resulted in the development of other ideas, some of them based on the practice of drilling and reaming through bushings, Fig. 57.

Among these are a hardened bushing located by means of gage blocks or depth gage, the Craley Master Toolmaker, having a bushing bracket and a movable table for holding the work, and the Moore Drilling and Layout Machine, having a bushing bracket movably mounted on graduated slides. The Moore machine has the distinctive feature that it includes a built-in rotary table, for angular spacing of holes.

All three of these devices have common disadvantages:

1. Their usefulness is limited, in general, to thin, flat pieces.

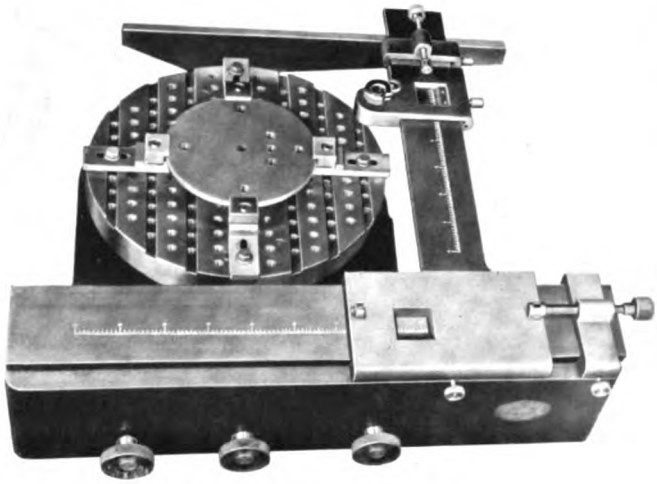
2. Their accuracy depends upon the closeness of fit of the reamer in the bushing, difficult to maintain, since the action of the reamer in the bushing wears both rapidly.

3. General lack of flexibility. They cannot be used for odd-sized holes unless a

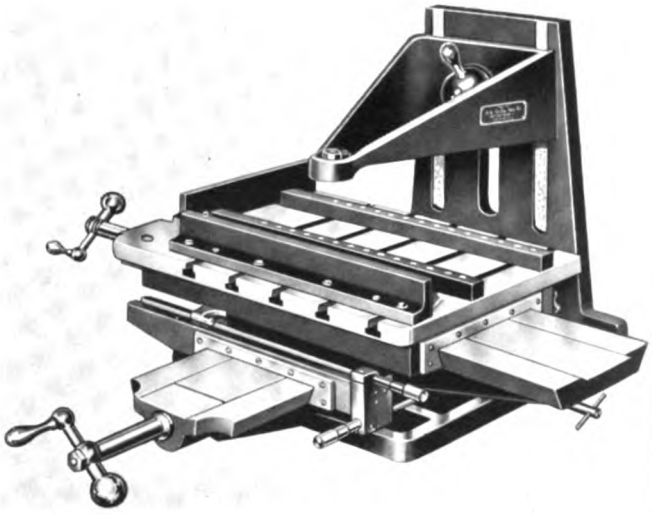
tremendous variety of bushings and reamers is provided. They are not suitable for boring large, odd-shaped pieces, or jigs or gages requiring holes in several directions.

In spite of their limitations, however, these devices signify an important trend in the progress of toolmaking. They show the tremendous pressure being exerted to find a device incorporating some easy, convenient way to make locational settings. They are stepping stones toward the development of the Jig Borer. In fact, the addition of an accurate spindle, to provide for single-point boring, is the only thing lacking.

During recent years, the development of better and harder materials for cutting tools, such as high-speed steels and the carbides, have given added importance to single-point boring. This already theoretically correct principle becomes more practical, not only for tool work, but for production jobs, as well.

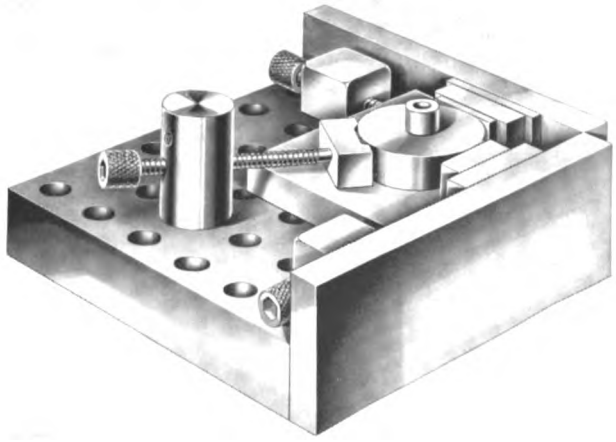


Moore Layout and Drilling Machine.



Craley Master Toolmaker.

Hardened bushing set on workpiece — position may be located with depth gage or size block.



THREE DEVICES EMPLOYING COORDINATE LOCATION

Fig. 57 — Although all three of these devices are subject to the limitations of high maintenance cost and low flexibility, they are important in that they show clearly the trend of mechanical thinking and the pressure being exerted to find a means for positioning holes by a measuring system extraneous to the workpiece.

Chapter III

WHAT DELAYED THE DEVELOPMENT OF THE JIG BORER?

RETROSPECTIVELY, it is not difficult to understand the inevitability of the development of the Jig Borer. The difficulty lies, rather, in understanding why it wasn't done before. Coordinate location and single-point boring — what could be more logical than to incorporate both these principles into a single, special-purpose machine?

The lag in the development of *engineered* hole locating equipment behind that for other parts of the toolmaker's job is, indeed, a subject for considerable speculation. Although lathes and planers were invented so long ago that no clear record of their beginnings exists, and machines for boring single round holes and machines for milling were invented prior to 1800, no recognized special-purpose machine for the *locating* or *spacing* of holes apparently existed prior to 1896. The modern conception of *high precision* was not designed into the locational feature until between 1915 and 1920.

Although knowledge of old-time machines has been dimmed by the passage of time, it is known that a French screw-cutting lathe existed prior to 1569.[1] It was a crude and cumbersome device, but its screw-cutting feature placed it far in advance of the potter's wheel, which undoubtedly was the first lathe. Other, improved, French lathes may be traced as early as 1740. By 1772 a crude slide rest was in use.[2]

The lion's share of credit for developing, reducing to practice and promoting the screw-cutting lathe, however, belongs to Henry Maudslay, an English mechanic and inventor, 1771-1831.[3] By 1797, he had built a lathe comprising all the basic elements of the modern engine lathe-headstock, tailstock, carriage and slide rest, and a geared lead screw. From that day to this, the addition of refinements has been steady and rapid.

Production features have been added, too. For instance, a vertical turret was added some time around 1840. By 1854, Robbins and Lawrence, predecessors of the present Jones and Lamson Company, were building commercially a horizontal turret lathe. In 1873, Christopher Spencer

[1] Joseph Wickham Roe, English and American Tool Builders.
[2] Ibid.
[3] Ibid.

had added cams to make the turret lathe operate automatically.

The Fay automatic lathe, which presents many cutting tools to the workpiece at one time, is an example of further improvement. The Gridley multi-spindle automatic and the Bullard vertical automatic multi-spindle lathes incorporate the "station" idea, the spindles themselves being indexed to bring the workpiece successively to one tool after another.

As with lathes, little is known of the planer's origins. Early records, around 1751-1754, indicate that the French also pioneered in this. English and American planers in the early 1800's apparently consisted of wheel carts, comprising the table, pulled back and forth under a tool head. Some early tool heads were designed to rotate, so a cut could be taken on the back stroke. In 1817, a Welsh inventor named Richard Roberts[4] built a planer which savors strongly of modern design — a table sliding on ways, a double column, cross slide and vertical tool slide. Refinements and improvements have been steady up to the present high-production, hydraulically-driven machines. Modern variations are open-side design, to accommodate large pieces, and the addition of milling spindles, to permit the rapid finishing of parts in a single pass.

The milling machine has more recent origins, also probably, French, around 1770. We have definite knowledge of milling cutters made by one Jacques de Vaucanson, some time prior to 1782. These cutters appear to have been turned on a lathe, then nicked, or chipped, by hand, to make teeth like a file. "There are a great many teeth, so that the cutter is, in reality, more like a coarse file than like the modern milling cutter, where each tooth becomes the substitute for a lathe or planer tool, and is capable of removing a substantial chip."[5]

The first great name in milling machines is that of Eli Whitney. Although widely known for his invention of the cotton gin, his fame better stems from his adoption of the principle of interchangeable parts to manufacturing processes. Whitney employed milling machines of his own make in the duplication of gun parts as early as 1818. An interesting sidelight on this was an artist's rendition of one of his machines, published in *Machine Design*, in January, 1930. This drawing shows a coarse-toothed cutter of modern design. The writer frankly doubts the authenticity of this. More likely, Whitney's cutters were not much more than rotary files.

Another early milling machine name is that of George S. Lincoln, whose company built the "Lincoln Miller" in 1855. A distinctive feature of this machine is a vertical adjustment of the spindle bearing to bring the cutter to the work. This type of machine was known as the "Lincoln Miller" even in Europe.

[4] Ibid.
[5] Brown & Sharpe Manufacturing Co. — Practical Treatise on Milling and Milling Machines, 1937, page 6.

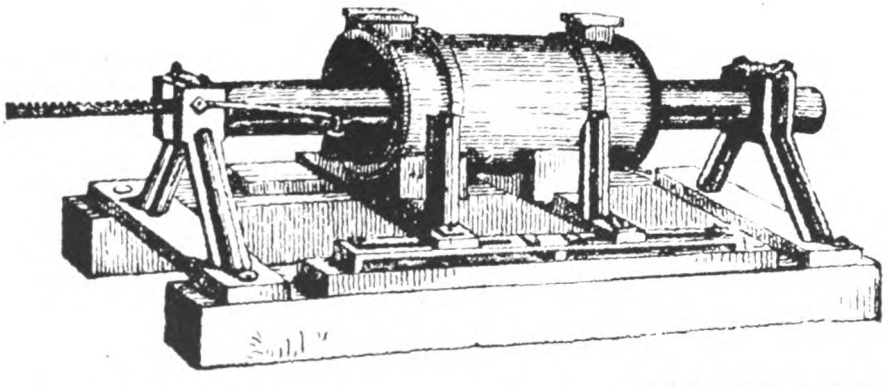
Vertical adjustment is also provided in a later, now considered conventional design, the "knee-type" miller, whose saddle and table move vertically, the spindle axis remaining stationary.

Inventions seldom derive from the sudden inspiration of any one man, but from the stimulation of circumstances. Furthermore, inventions of specific devices frequently open windows upon avenues of new ideas. Invention begets mechanical progress, which, in turn, restimulates invention, recalling the old question, "which came first, the hen or the egg?"

Progress of machine tools and manufacturing from 1750 to 1945 provides a good parallel to this question. Firearms, watches, clocks, locks, instruments, automobiles, and airplanes have all stimulated the invention of methods to produce them. Inversely, refinements in methods have provided the means for their further development. In fact, without the means for producing them, the invention of many devices would have been fruitless: they would have died a-borning. Credit for our progress cannot be attributed to any one, or few, manufacturers, workers, users — all have participated, both in the demand and in the benefits.

There are a few cases, however, of inventions made to solve some specific problem. Some of these have influenced the solution of other, similar problems; others have ended, substantially, with the solution of the specific problem in hand.

A case of the latter kind is Whitney's invention of the cotton gin. A casual conversation with some cotton-growers, discussing the problem of separating cotton from its seed by hand, definitely stimulated Whitney's mind to its solution. The influence of his invention as applied to this particular job has been enormous; it has not been adaptable to other kinds of work, however, and has, therefore, not directly



Roe, English and American Tool Builders, 1916

Fig. 58 — Ancestral parent of modern Jig Borer, built by John Wilkinson, of Bersham, Circa 1775, specifically for boring steam cylinders. Probably embodies the first single-point boring tool.

led to the solution of other problems.

James Watt's reciprocal engine, on the other hand, provided the opportunity for an invention which radically changed mechanical practices and set the stage for boring machines. Watt's chief difficulty was the lack of any boring machine capable of making round holes. Boring machines of his day were, in effect, large reamers, guided by the rough casting, producing errors of as much as three-eighths of an inch! A mechanic-friend, John Wilkinson, of Bersham, conceived the idea of guiding a boring bar from both ends, *independently from the casting*, Fig. 58, the original single-point boring tool!

Wilkinson's contribution, in the light of present-day knowledge, appears exceedingly simple. Actually it was a tremendous forward stride. It embodied, apparently for the first time, the idea of *generating* an internal cylindrical surface by boring around a fixed axis. This simple invention was an enormous contribution to mechanical progress. Without it, a host of present-day devices, especially those embodying hole *location*, would be impossible to mass-produce.

Because of the mutual stimulation of all the various phases of allied products and processes, their invention can usually be expected to advance on a common front; progress of all phases is about the same. Yet, peculiarly, the hole locating part of the toolmaker's job, for a hundred years, did not progress along with the other phases of his work. During the period of the development of standard machine tools, such as lathes for generating rounds, planers and shapers for producing flat surfaces, and milling machines for duplicating various predetermined, formed shapes, very little was done to promote facilities for making a hole in the right place, or two holes *correctly spaced.*

The reasons for this lag are not readily discernible. Surely, the demand existed. For a hundred years, mechanical devices have been made interchangeably, requiring accurate duplication of hole position. Thousands of toolmakers have spent countless hours on the tools required — laying out, indicating, wiggling, setting buttons, and laboriously drilling or boring holes to accurate location. It is amazing that among the thousands of inventive minds employed, few have seen sufficient incentive to devise means for hole location.

It may be that the costs of this part of the job were hidden too obscurely. The overhead expense of the toolroom is usually regarded as a necessary evil while excessive production costs, which directly affect profits are immediately pursued and ferreted out. Tooling has been left to craftsmen, not cost-minded. Nor are they production-minded. As a result, they do not press management for modernization of equipment, as production men do. It is

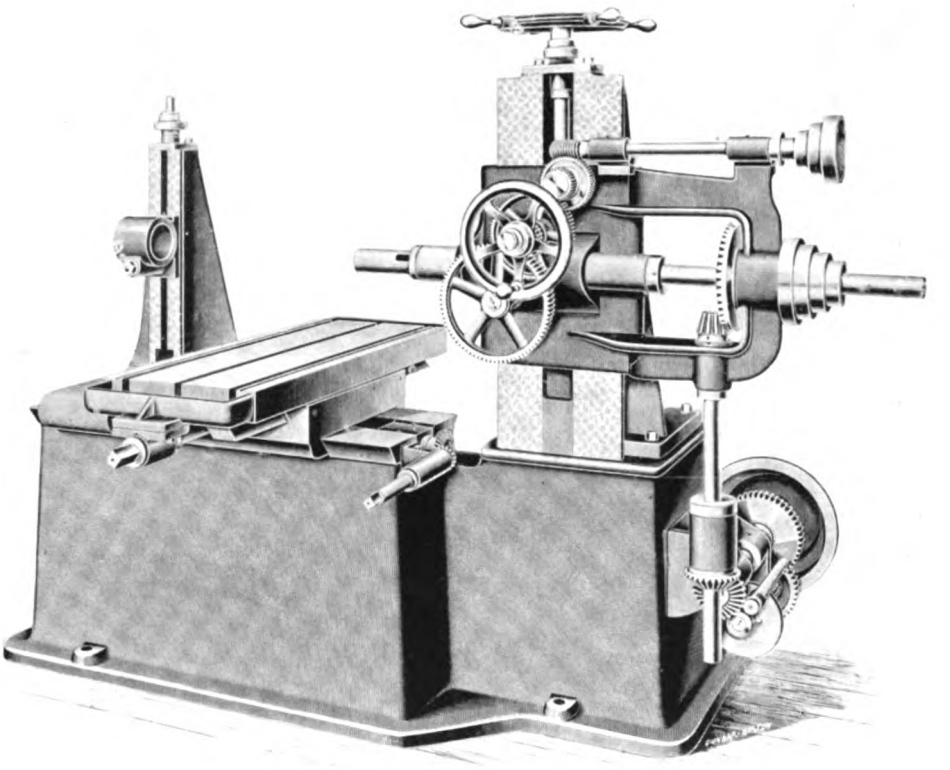


Fig. 59 — The first horizontal boring machine built for Charles A. Clarke, late of the Universal Boring Machine Company.

not uncommon to find manufacturing plants equipped with ingenious and highly modernized production processes while the toolroom is deplorably out of date. Since hole location is only a part of the toolmaker's job, it is assumed that this problem was neglected along with the rest.

A further plausible reason is the barricade of secrecy built around skilled crafts by their practitioners, in order to maintain the father-to-son tradition. Jewelry, watchmaking, silversmithing, the diamond industry and other handicrafts have been subject to self-imposed restrictions of this sort. They have perpetuated outmoded techniques.

Around the end of the nineteenth century, however, a few forward-looking individuals started giving this problem some attention. Typical of these was Charles A. Clarke, late of the Universal Boring Machine Co., Hudson, Mass. After traveling a great deal among machine tool builders and toolmakers, both here and in Europe, the demand for a toolroom Boring Machine seemed to him to warrant the building of one. The result is shown in Fig. 59, built for Mr. Clarke in 1896.

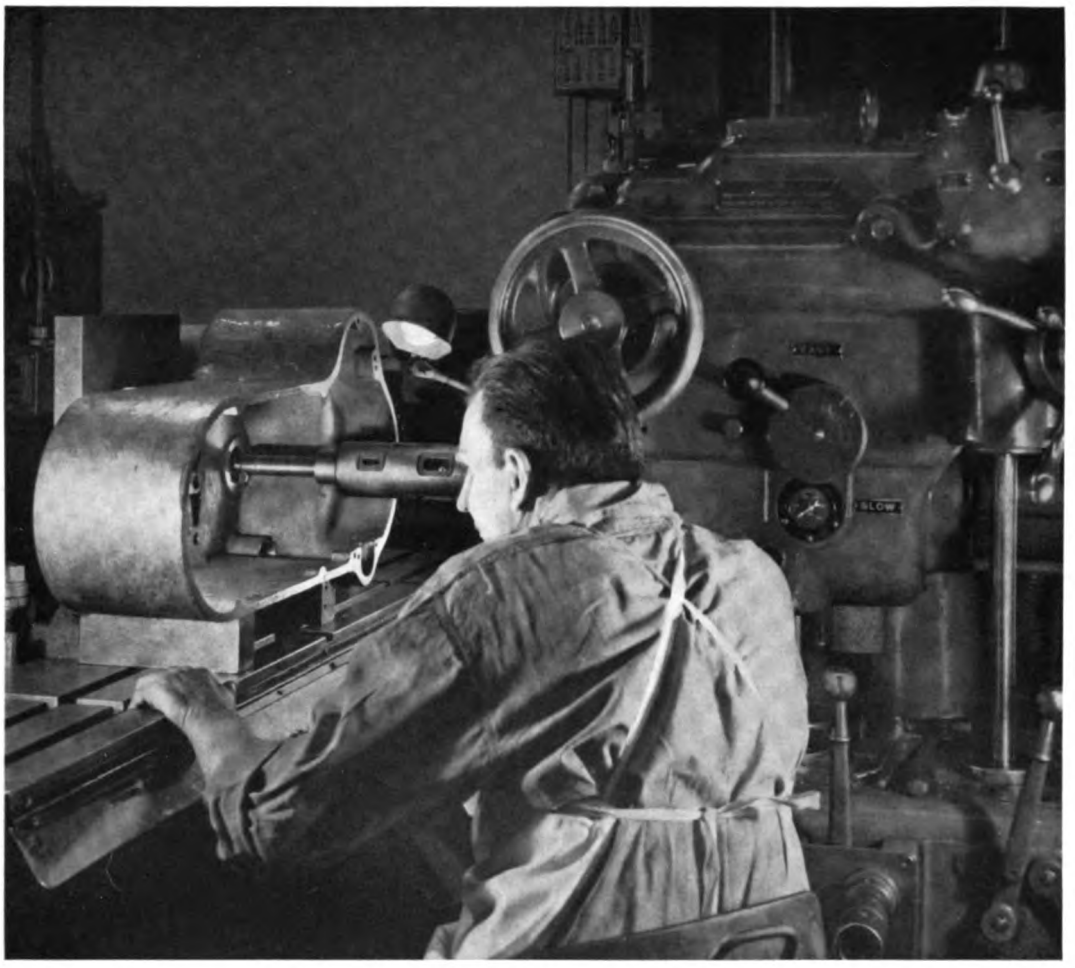


Fig. 60 — Although unsuitable for small, medium-sized or flat pieces, horizontal machines are excellent for box-shaped jigs or machine parts requiring holes in many directions.

The writer is not prepared to state that this is the first machine of this general design to be built; if not, it at any rate is undoubtedly typical of its day. Its inspiration appears to have been derived from the Lincoln Miller, inasmuch as the spindle moves up and down on the column. Although this artist's rendition does not show measuring devices, the writer is assured by present company officials that dials, on the up and down and cross feed screws, graduated in thousandths of an inch were used to measure distances moved. It was clearly Mr. Clarke's intent to overcome the difficulty of locating holes by buttoning or layouts.

Although built for toolroom use, this horizontal type of machine is not too convenient for small, medium-sized, or flat pieces. Moreover, the machine is too large, requires excessive floor space and is too expensive for small toolrooms.

It is excellent for some types of work, however, such as large box jigs or machine housings, Fig. 60. It is ideal for tools which can be strapped directly to the table and require holes in many directions.

The horizontal boring machine of Mr. Clarke's day probably was not capable of high precision, in terms of "tenths". It would probably *repeat* a position consistently within ±.0005″ or ±.001″. Knowing the difficulties encountered in the making of precision lead screws, the writer frankly doubts whether it would *measure over its entire range* much closer than ±.002″ or ±.003″.

In fact, as recently as 1912 and 1917, prominent authorities on toolmaking practice agreed that the lathe faceplate was the most accurate place to bore holes in small tool parts.

For example, Fig. 61 shows one method, described in "Accurate Tool Work", Good-

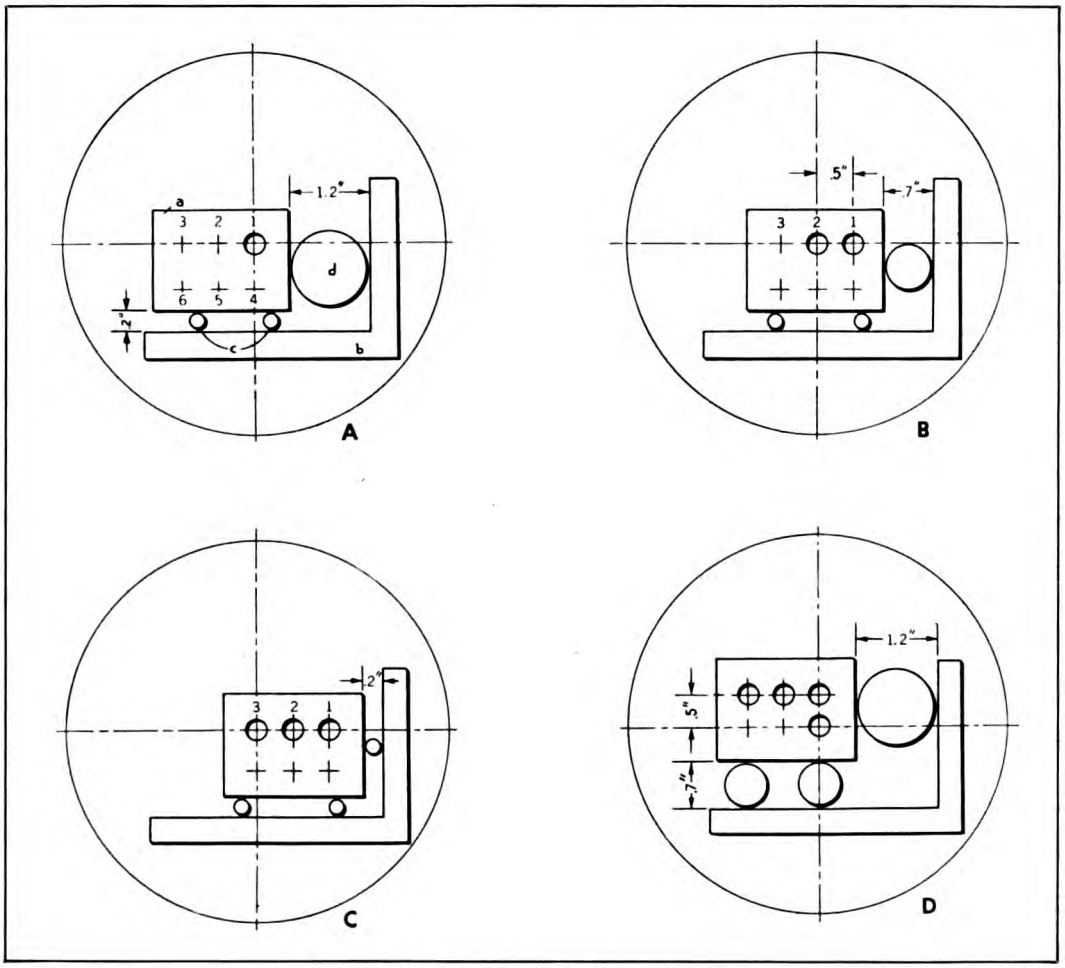


Fig. 61 — Discs for setting master plates for boring, 1912.

rich & Stanley, 1912. In this case, the workpiece movements with respect to the center of rotation are set by inserting discs, C and D, between the work and a right-angled piece, B.

In 1917, Joseph V. Woodworth, author of "American Toolmaking and Interchangeable Manufacture", page 45, states, "There is only one method for locating bushing-holes in small and medium-sized jigs accurately and expeditiously . . . and is known as the "button method".

Soon after this, complete machines for Jig Boring were built in Europe by the Société Genevoise d'Instruments De Physique (SIP), of Geneva, Switzerland, and in this country by the Pratt & Whitney Company, of Hartford, Connecticut.

Switzerland, famous for its many generations of fine watch makers, is the natural breeding ground for the beginnings of Jig Boring. It is interesting to note in passing, how many machine tool principles were originated by the French, see pages 52 and 53, and by the Swiss.

The first locating machine was developed in Switzerland about 1910. This was not a complete Jig Borer, but only enabled prick-punching the center points of the gears on small watch components. It was a small and very light machine, providing a steady work table and a cross-slide attachment carrying the punching tool. The latter comprised a vertical spindle sliding in a guide borne by the upper slide and terminated by a sharp point to spot the desired locations of the holes in the workpiece.

The cross-slide device, having a range of four inches, was controlled by micrometer screws. The punching attachment was interchangeable with a control microscope for measuring purposes, and, optionally, with a very light drilling attachment, having a maximum capacity of 1 mm., or about .040″ diameter drills.

After the end of the war (1914-1918), SIP began developing a real Jig Borer, based on the principle of the first locating machine, but with important design changes. The new machine was not limited to watch makers' work, but was large enough to perform general mechanical and tool work. It had a capacity to drill 1¼″ holes in cast iron. The spindle no longer interchanged with other tools, but was regarded as a fixed part of the machine.

Since a cross-slide device for moving the workpiece or the boring head in two perpendicular directions was not regarded as suitable for the best accuracy in the required size, a new design was adopted. Two distinct slides were provided, one carrying the work table and the other carrying the vertical boring spindle. To augment the vertical travel of the spindle without undue loss of accuracy, the cross-rail carrying the spindle housing was also vertically movable. This design is still used on the present SIP Jig Borers.

The necessary steps were taken to insure the manufacture of accurate lead

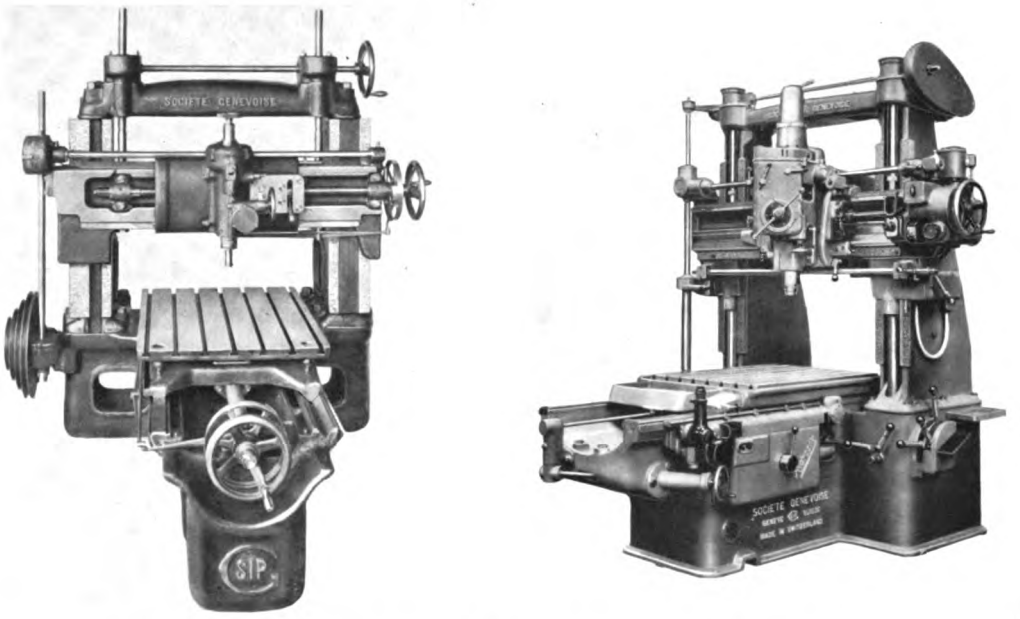


Fig. 62 — The old and new in Swiss Jig Borer design. Left, the first machine built in 1922 with compensated lead screws for measuring; right, current "hydroptic" design, so named from the combination of hydraulic and optical features.

screws for moving the work table and the boring head, as well as for securing an accurate displacement in height of the cross-rail along the uprights. For many years SIP cooperated on the manufacture of the first locating machine by supplying the manufacturers of that machine with the necessary precision scales and micrometer screws. Since they have specialized in the fabrication of such accurate screws for their dividing machines, SIP encountered no particular difficulty, except in the case of long screws which control movements over long distances. This was surmounted by incorporating automatic compensators, permitting extremely accurate settings.

The first machine of this new design, with a range of 12 x 16 inches, was built by SIP in 1922, Fig. 62. This machine proved to be quite accurate, but its productivity was limited by a too-small speed range. Anti-friction bearings not yet having been sufficiently developed for high-precision purposes, the spindle was guided by closely fitted plain bearings, set just free enough for a thin lubricant film. For this reason it was not possible to drive it fast enough. SIP kept this machine for their apprentice school, where it is still in use.

In 1925, SIP built a second model of the Jig Borer with several improvements, the most important being a single-drive pulley and gear box to supplant the step pulley and augment the speed range, and two

boring heads, a light one for high speeds and a husky one for the heavier cuts at lower speeds. From this type were developed the Nos. 4, 5 and 6 SIP Jig Borers, with ranges of 16″ x 24″, 24″ x 32″, and 40″ x 52″, respectively. Their world-wide use attests the necessity for these machines.

In 1934, SIP completely redesigned their measuring equipment and spindles, at the same time redesigning and modernizing overall design.

The micrometer screw was replaced by optical measuring equipment (standard scale and microscope) and a hydraulic drive for the work table. This proved to be a decided improvement on large-sized machines, overcoming the difficulty of producing and maintaining stability in lead screws of excessive length. The hydraulic drive enables quick settings over long distances of table travel. From this combination of hydraulics and optics, SIP derived the trade name Hydroptic, Fig. 62.

In addition, the plain spindle bearings were replaced by special anti-friction bearings. This permitted high spindle speeds with little heating and far better rigidity.

SIP Hydroptic machines are intended both for boring and milling. It has been built in two different sizes: primarily 36″ x 28″ and, since 1939, 56″ x 40″.

It is an interesting commentary that over 2000 SIP machines of different sizes have been built. The SIP Company is held in high regard for the progressiveness of its management and methods.

The story of pioneer work on the Jig Borer in America is closely interwoven with the development of the Pratt & Whitney Measuring Machine and the evolution of interchangeable manufacture. This phase begins in 1882 with the "Report of the Committee of the Master Car Builders' Association on Standard Screw Threads", to their Annual Convention. The research leading to this report had resulted from the fact that "bolts and nuts made by different manufacturers were not interchangeable, which caused a great waste, detention, and expense in making repairs . . . Manufacturers of taps and dies were working to different standards."

Pratt & Whitney undertook to test which standards were correct. They procured the best standards available and had them measured by what were considered the most reliable measuring machines and instruments in the country. Not only were all the standards different, but no two measuring instruments would measure the same standards alike.

Their investigation convinced them that neither a final standard nor any instruments for sub-dividing it existed. Because of Pratt & Whitney's prominence in the manufacture of taps, dies, gages, and instruments of precision, they determined, to "go to the bottom of the subject, and to lay a foundation against which no wind or wave of doubt or uncertainty could prevail".

Happily about this time, the company

became acquainted with Prof. W. A. Rogers, Professor of Astronomy at Harvard University. Interested in precise measurements, he proposed a measuring system which eliminated the defects of other measuring devices. Two machines were built, one of which remains in the possession of the Pratt & Whitney Company and the other of the Smithsonian Institute, Washington, D.C.

Thus "the man of science turned his attention from the planets and the measurement of distances counted by millions of miles, to listen to the imprecation, perhaps, of the humble car repairer lying on his back and swearing because a 5/8" nut — 'a leetle small' — will not screw on a bolt — 'a trifle large'. It is a striking example of the assistance which science can give in conducting the practical affairs in life."

The standard bars in the two Pratt & Whitney Measuring Machines were of the line measurement type. Graduated by Prof. Rogers and sent to Washington for comparison with standards at the Bureau of Weights and Measures, they were reported to "differ from the Imperial Yard by a quantity less than the certainty by which such comparisons can be made — viz. — .00001"."

It is not sufficient to possess basic standards. They must be reproduced and distributed in usable form. This Pratt & Whitney has done in the form of gage blocks, or end measures, "made so carefully that end-measure pieces representing any subdivision of a foot, and taking any of these sizes from a quarter inch to four inches, varying by sixteenths, the sum or combination of them, taken at random and in numbers sufficient to constitute the length of a foot, will be found to produce in the total addition, exactly the same result" — ASME, report from Committee on Standards and Gages, 1882.

Soon after the turn of the century, Pratt & Whitney undertook to equip several domestic and foreign arsenals for manufacturing small arms. Included were large quantities of jigs, fixtures and gages where holes had to be drilled and reamed or bored accurately in predetermined locations. The "Button" method being slow and uncertain, Pratt & Whitney developed a machine based upon the principle of the measuring machine for location. It was equipped with a precision tool-carrying spindle for drilling and reaming or boring the holes in the jigs and fixtures. The first machine was completed in August, 1917.

Foreseeing the convenience of a vertical spindle, Pratt & Whitney deviated from the conventional horizontal spindle design of lathes, horizontal boring mills and milling machines then in use. A collet mechanism for holding and quickly changing tools was also added.

On the basis of some thirty years' experience in making precision screws, gages, and measuring machines incorporating both "line measurement" and "end meas-

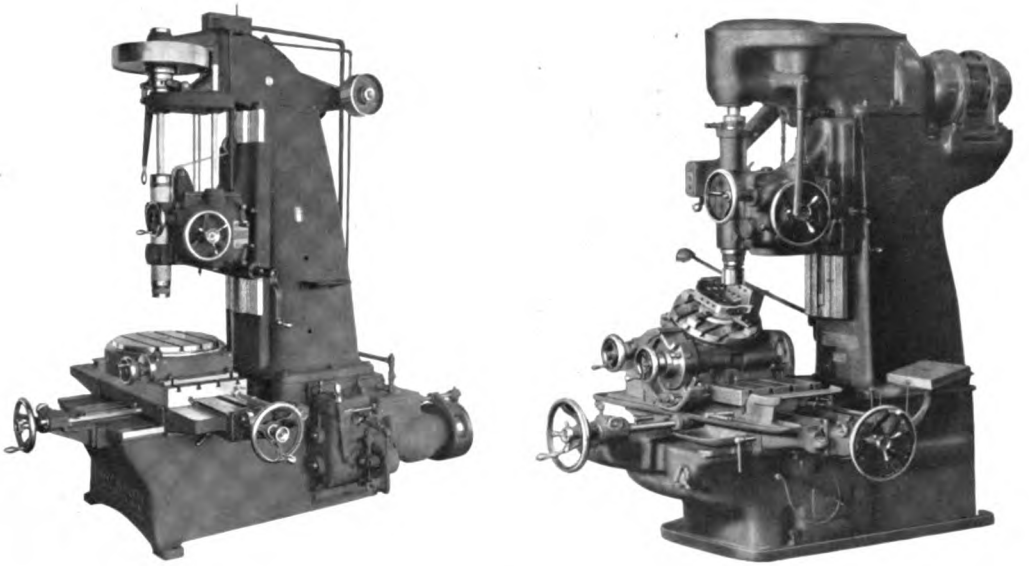


Fig. 63 — The old and new in Pratt & Whitney Jig Borer design. P. & W. have been the leading proponents of the end-measure measuring system.

urement" methods, it was decided to use end measures for the even inch spacings, and a micrometer screw for the subdivisions. Dial indicators were employed to establish zero positions, and to show that the work-carrying slides had actually moved as indicated by the measuring instruments. Rotary tables were also provided for accurate circular indexing.

The reception extended to Pratt & Whitney Jig Borers, evidenced by the results obtained by thousands of users, has clearly justified the conception and creation of this machine tool.

The Pratt & Whitney Company today gives full credit for the conception and naming of this machine to a former vice-president and works manager, B. M. W. Hanson, also inventor of the Pratt & Whitney Spline Miller, Thread Miller, Vertical Surface Grinder, and Vertical Shaper.

Mr. Hanson often spoke about building a machine for boring jigs and fixtures. When the idea had reached the stage of a blackboard sketch he was asked by colleagues what he proposed to name the machine. He replied, with true Scandinavian directness:

"We'll call it a Yig Borer!"

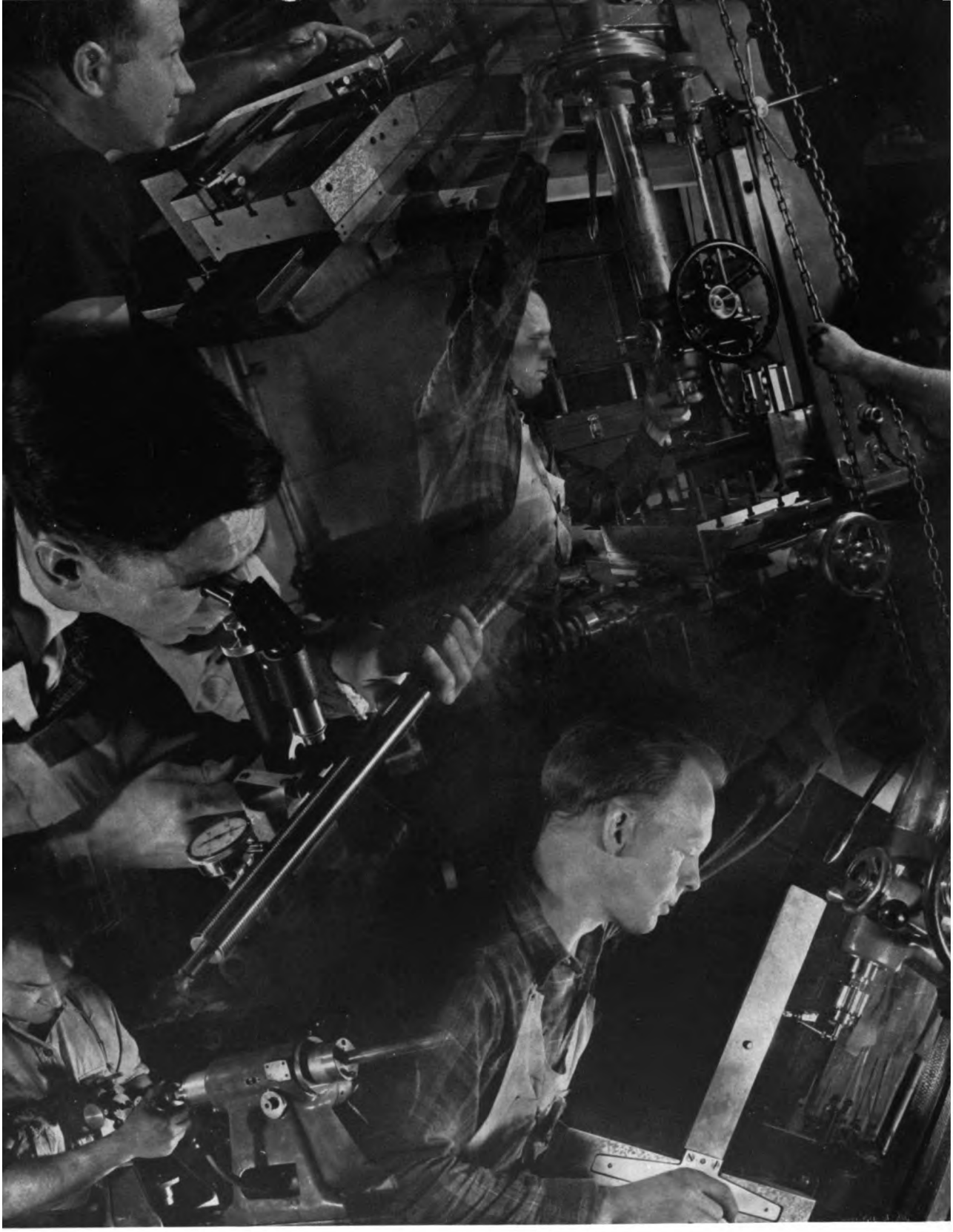


Fig. 64 — Assembling a Moore Jig Borer.

Chapter IV

DEVELOPMENT OF MOORE JIG BORER

INVENTORS are lazy men at heart. All inventions are stimulated by the desire to make some tough job easier.

Inasmuch as The Moore Special Tool Company started its existence as a tool shop, it very soon became aware of the toolmaker's irritation over the hole locating problem. It appeared that energy put into its solution would be well spent.

The increasing demand for greater accuracy and speed in the boring of holes in jigs, fixtures, dies, gages, models, experimental work, and special machine parts showed clearly the real need for a small, accurate Jig Borer suitable for such work. In 1930, Moore tackled the job.

Such a Jig Borer should have every control convenient to the operator's sitting position, yet have ample capacity for the average work found in toolrooms and jobbing shops making tools and dies for small and moderate sized parts, required in clocks, locks, small electric devices, typewriters, adding machines, toys, instruments. It should be sufficiently sensitive to drill small holes, $\frac{1}{32}''$ or less, yet rugged enough to be accurate under heavy cuts. It should be convenient enough for rapid, high-accuracy, small-lot production boring, eliminating expensive jigs. It should also solve the problem presented when, although the *quantity* is large enough to warrant the expense of a jig, the *accuracy* attainable from a jig is not good enough. Such parts should be single-point bored.

The basic requirements of a Jig Borer are very simple. A rigidly mounted spindle and some accurate means for moving the work are all that is required.

The process of attaining these requirements is not simple. That the operator may do his job the *easy* way, the Moore Jig Borer is built the *hard* way. It is not feasible merely to convert some existing machine, such as a milling machine or lathe, to a Jig Borer by adding measuring devices. Most attempts have proven the fallacy of this, especially for high precision work. The basic design of each of these machines, although excellent for its own purposes, is inherently unadaptable to jig boring, and cannot provide an accurate foundation for the measuring system or the spindle, regardless of workmanship.

General Design — In the consideration of possible variations in design, a precision Jig Borer requires a comprehensive design analysis, embracing accuracy, stability, speed, flexibility and operator convenience.

In building precision machines one of the first steps is to avoid the preconceived notion that cast-iron and steel are fixed and solid. Actually, a precision machine is more like pieces of rubber screwed together, each squeezing, expanding or bending exactly in proportion to stresses or temperature changes imposed upon it.

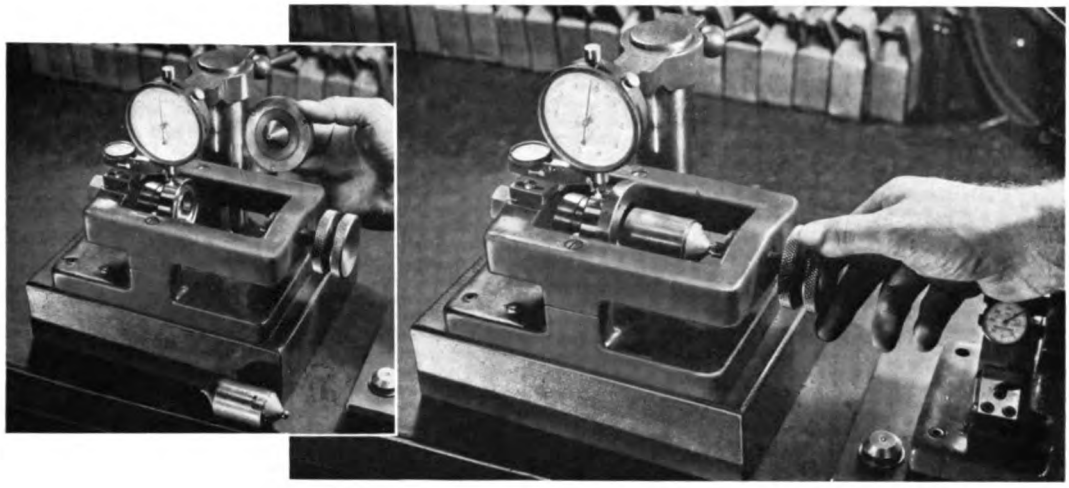
It is generally conceded that, for its intended work, the Jig Borer table should be horizontal and the spindle vertical. The table and cross slide should be supported on amply-proportioned base and ways, and should not be movable vertically at the expense of accuracy, Fig. 91.

To provide best flexibility, the base and column are made in two pieces. Their juncture provides the proper surfaces for final scraping to square up these members. In addition, the machine range may be increased by inserting riser blocks without dangerously compromising accuracy, Fig. 145. This is of enormous value in cases where users must have additional height. One piece (base and column) construction obviously will not permit this.

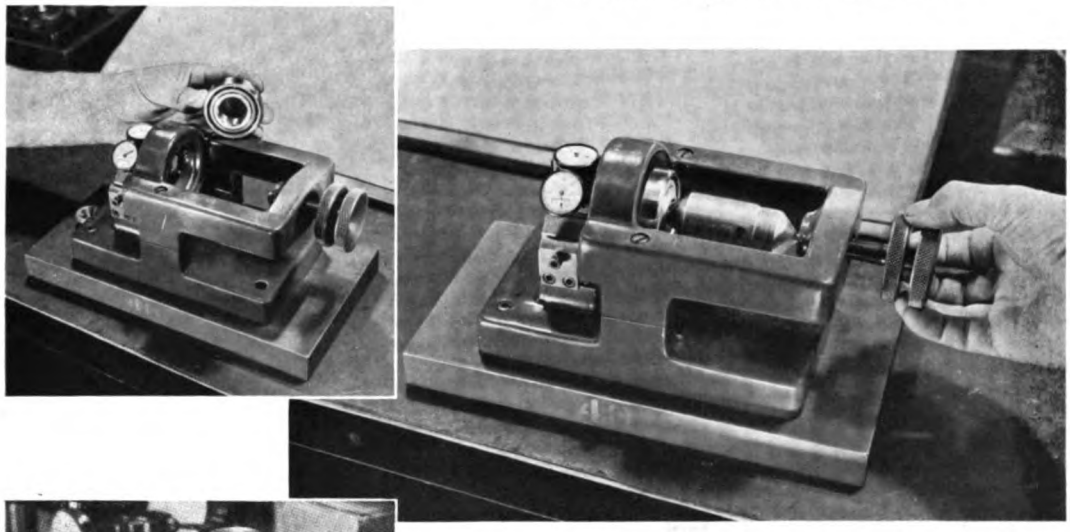
Dimensional stability is of further prime importance. All heat producing mechanisms should scrupulously be isolated from dimensional control members such as base, column, and spindle housing. Unfortunately, some designers still deprecate *thermal* effects. This attitude reflects either a lack of background in the design of precision machines, stubbornness, or a desire to follow the line of least resistance and ignore the resulting distortion. A flagrant example is the attempt to streamline the machine by concealing drive motors and hydraulic systems in the base and column or even in the main spindle housing. Iron and steel expand .000006″ per inch of length per degree Fahrenheit, temperature increases of 10 degrees, barely perceptible to the feel, expand the spindle housing beyond the limits of accuracy guaranteed in the machine! Cases have been observed where temperature rises have been as much as 20 or 25 degrees in dimensional control members.

Another problem is that of spindle, quill and quill housing design. Some designers feel that the housing should be fixed, and that the quill only be movable, making quite a point of the fact that fewer movable parts promote better rigidity. However, most of the loss in rigidity occurs in the spindle, quill, and at the juncture of quill with housing, especially when at maximum quill extension. In this design it is impossible to obtain adequate height range without excessive quill extension.

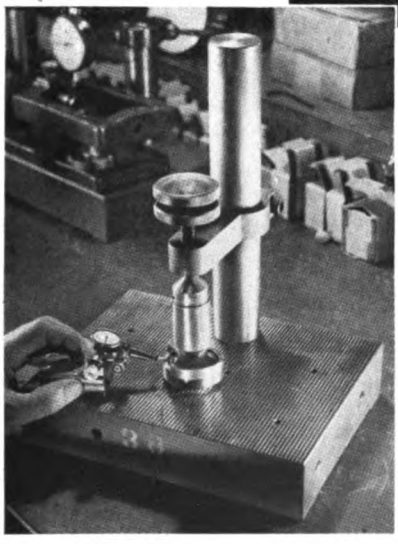
The advantages strongly favor moving both parts. The movable head may be rigidly "fixed" at any desired position by clamping. More than that, it may be fixed at the proper position for each specific job, permitting the quill to project from its



Checking concentricity and wobble of outer race.



Checking concentricity and wobble of inner race.



Checking axial preload.

Fig. 65 — Inspection procedure for ball bearings. Calibrated spring cartridge applies load in exact center of bearing. All tests are made under conditions closely simulating actual assembly.

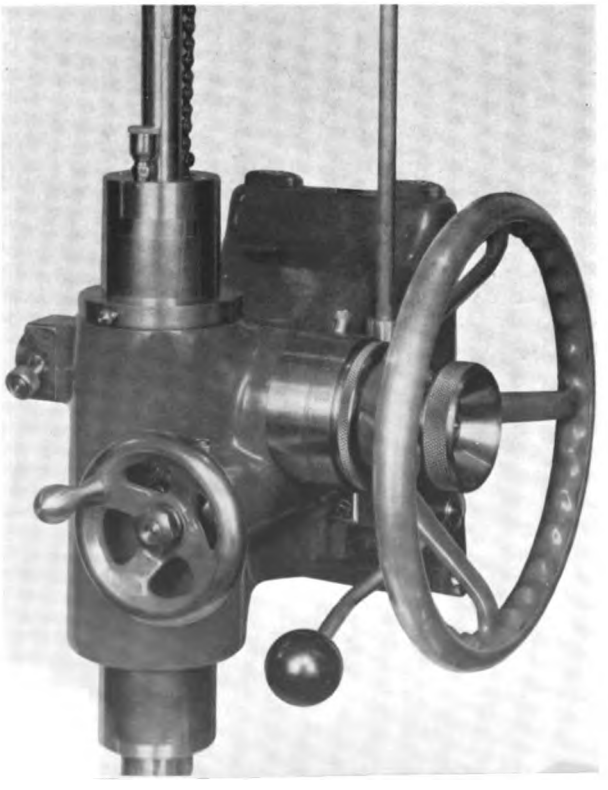
support a minimum amount, securing maximum rigidity. This design produces by far the better flexibility, and a much greater range of travel with the least compromise with accuracy.

Once the major design has been established, careful control must be exercised of all details relating to it.

The Spindle and Quill — Plain-bearing spindles, see page 37, with their attendant maintenance difficulties, are unsuitable for accurate single-point boring. The necessary oil film prevents rigid contact with the bearings. This always results in a certain amount of looseness, or play; the axis of rotation does not stay in the same place.

The only known type of bearing to eliminate this play is the *preloaded anti-friction bearing*. Grinding spindles require great rigidity; single-point boring requires even greater rigidity, because of the higher cutting pressures. Moreover, the introduction of high-speed steels, and more recently, tungsten carbides, as cutting tools, increases the importance of rigidity in the boring spindle. Furthermore, the wide variety of sizes of holes to be bored necessitates an enormous speed range. Plain bearings, if set tight enough to give good rigidity at low speeds, overheat to such an extent at high speeds that accuracy control is lost.

Fig. 66 — Quill and quill bushings are hardened, ground and lapped to gage fit. Setting rack below surface eliminates slot in bushings, permits line lapping of true, round hole.



For these reasons the Moore Company, pioneered the use of preloaded ball bearings in the Jig Borer spindle. Their soundness is fully attested by their exceptional service under tough conditions, and the fact that they are now employed, not only by other Jig Borer builders, but in all types of machine tools.

When the first Moore Jig Borer was built, production of high-precision ball bearings was limited to few manufacturers, and careful inspection and selection of bearings was necessary. Checking devices for this are shown in Fig. 65. To this day, every ball bearing built into a Moore Jig Borer undergoes rigorous inspection to insure parallelness of spindle axis with quill travel and absence of axial camming.

The sliding way provided for traversing the spindle is fully as important to spindle rigidity as the spindle bearings. The design

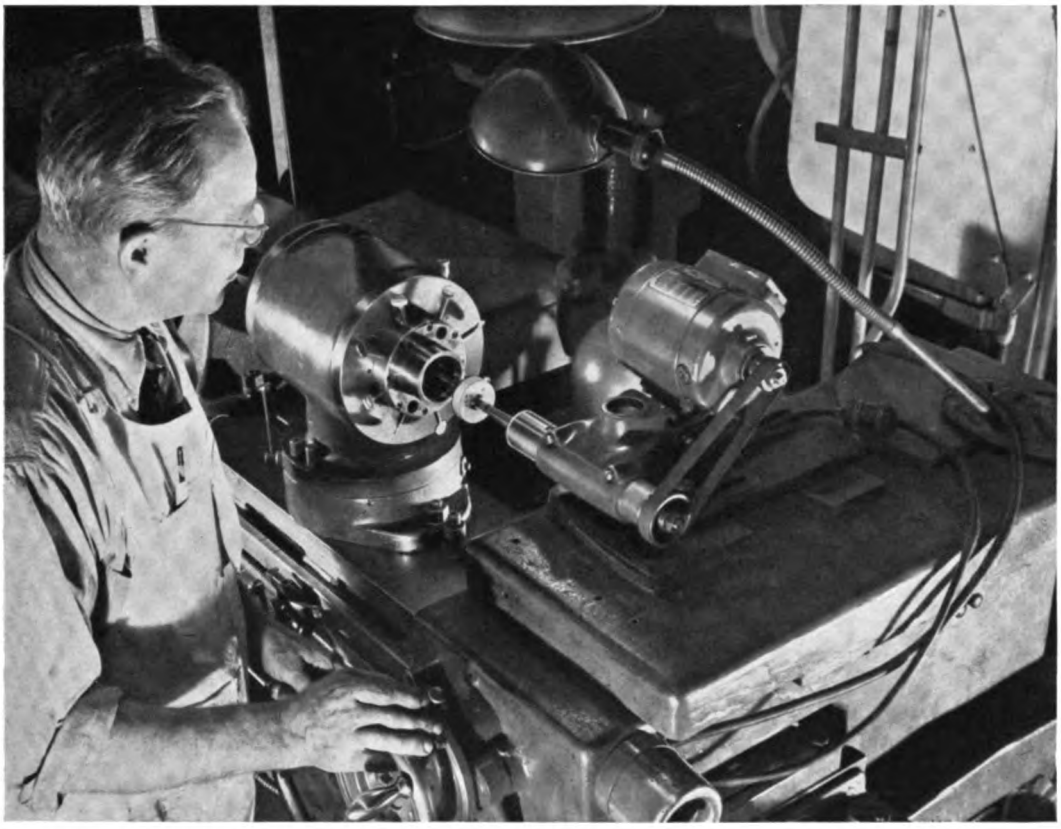


Fig. 67 — Hollow internal grinder work spindle insures perfect alignment of ball bearing pockets. Work head is turned around to present either end of quill to grinding wheel without disturbing setting.

established for the Moore Jig Borer has proven eminently satisfactory. The spindle bearings are mounted in a hardened, ground and lapped quill, which slides in hardened, line-lapped bushings. These parts are lapped to a gage fit, resulting in the smallest possible clearances, eliminating sideways movement and wear. To permit full lapping of the bushings, the rack is set below the surface of the quill. No slot is required in the bushings. See Fig. 66.

An interesting problem in the manufacture of the quill is that of attaining perfect alignment of the ball bearing pockets in both ends. A special hollow spindle, mounted in preloaded ball bearings, holds the quill in the internal grinder, Fig. 67. After grinding one end, the entire grinding spindle is turned around to present the other end to the wheel, without disturbing its setting or axis of rotation.

The Measuring Method — Since the Coordinate Location System is the ultimate locational principle, the measuring method should be so designed as to promote its fullest use, and, therefrom, derive its greatest possible benefits.

Three distinct methods or principles of

linear measurement are commonly used in machine shops and toolrooms:

1. The graduated scale

2. The size block or end measure

3. The precision lead screw or micrometer screw.

All three methods have their advantages and their disadvantages.

The scale has the advantage of not being subject to wear. However, in working to "tenths", extremely fine lines must be used, requiring optical provision for reading. The necessity for scales or end measures is recognized, especially in large machines requiring long travels. Here, accurate lead screws are difficult to produce and stabilize. In the average shop, however, producing mostly small and medium-sized work, scales are unnecessarily slow and place an exacting strain on the operator.

The end-measure method will produce accurate results provided all conditions are right, but these conditions are many:

1. Blocks alone are insufficient. A micrometer screw must be used to break up the inches into "tenths" and a dial pressure indicator to keep constant pressure on the end measures.

2. End measures are subject to expansion or contraction from temperature variations and therefore must be maintained at constant temperature. This is difficult, since they must be exposed to the air for accessibility.

3. Contact between blocks must be perfect; the smallest particle of dirt will alter the setting. Abrasive particles cannot be avoided when drilling, boring or grinding.

4. The end-measure method is more complicated and requires more skill than either of the other two methods.

5. It is the slowest because of the many motions required for a single setting.

Accurate lead screws overcome all these difficulties. They also offer advantages not commonly recognized.

The best Jig Boring procedure is to spot, drill, and rough-bore *all* holes in a given piece consecutively, *before* finish-boring *any* of them, to minimize operator errors and errors caused by stresses or temperature changes. The best incentives to prevent the operator from short-cutting this procedure are speed and ease in making table settings. These incentives should be built into the machine. Lead screws are obviously the answer; the same device which *moves* the table also *measures* that movement. Lead screws can be set faster than tools are changed. It is quicker to follow the best practice than to finish-bore each hole before roughing the next.

This procedure contributes to overall accuracy in many ways:

1. By minimizing operator errors. Most operator errors are of one full turn of the micrometer screw, of .025″ or .100″, or by misreading by .010″, seldom small errors of .0005″ or .001″. To prevent this type of error, all holes should first be *lightly*

spotted. When going over the settings to re-spot deeper, errors made on the first setting are sure to be detected, since the spotter will not line up with the original spot, warning the operator to check his reading between cuts, Fig. 161.

2. By avoiding errors caused by stresses from roughing cuts. After all the heavy roughing is done, the original setting, or "pickup", is checked, then finish cuts taken. The roughing is now out of the way, and the operator can go ahead with the finishing without fear of disturbing the work, or shifting it under its clamps (see also page 133).

3. By avoiding errors caused by temperature changes. Roughing the piece often heats it considerably, and if the hole is immediately finish-bored, subsequent shrinkage of the piece alters location. Roughing all the holes first gets the heat out of the way; finish-boring can now be done under uniform temperature conditions.

In addition, the screws are enclosed in the body of the machine, and, therefore, not subject to room-temperature changes, as are exposed blocks or scales.

These factors all reduce human errors and the need for great skill, showing the lead screw to be by far the most satisfactory measuring method for the small or medium-sized Jig Borer.

To obtain good results, however, the lead screws and their mating nuts must be made to the highest standards of refinement. Neither milled threads nor threads chased in a lathe will produce sufficiently accurate leads or good enough surface finishes for high precision measuring. This leaves one alternative — use of hardened, thread-ground screws.

In this country, the Moore Company pioneered the use of the thread-ground lead screw as a measuring device in a machine tool in 1930. Any question of the soundness of the principle of measuring with lead screws was soon dissipated. Table settings are made rapidly and accurately. The wear problem is overcome by hardening. Tests made on lead screws of Moore machines in constant use for five or ten years show that the wear is negligible.

Manufacture of Lead Screws — Having established these facts, the Moore Company undertook to produce the most accurate lead screws possible. A thorough study of the problem and the development of new techniques to solve it, result in the grinding of lead screws in the Moore plant accurate to 0.0002″ in 16″.

Effect of Temperature — Temperature control is a major problem. A piece of steel 10″ long expands .00006″ for each degree Fahrenheit of temperature rise. Changes of 5 or 10 degrees, barely perceptible to the fingers, cause startling dimensional changes, far in excess of permissible tolerances.

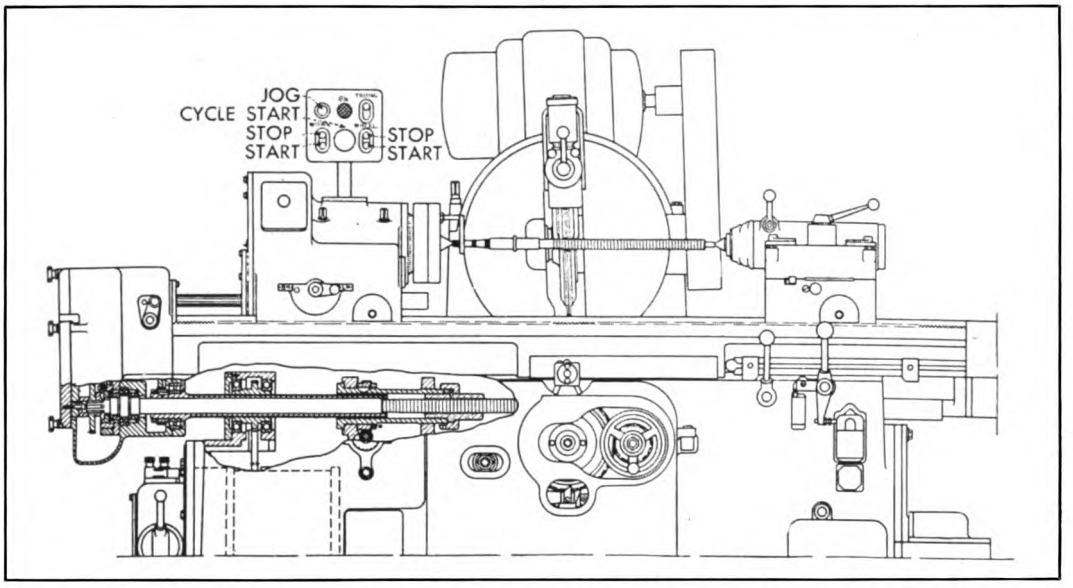


Fig. 68 — Basic elements of thread grinder, showing master screw geared to work spindle and controlling longitudinal movement of headstock. Pitch of master screw directly controls lead of workpiece being ground. Errors in master screw are reflected as lead screw errors in workpiece.

Temperature effects appear in many places — in the grinding machine, checking devices, and in the workpiece, during both grinding and checking. These effects are all interrelated; none can be considered independently from others.

The schematic view of a thread grinder, Fig. 68, shows how the master lead screw, geared to the work spindle, advances and rotates the workpiece. Since the pitch of the master screw controls that of the workpiece, any pitch error in the master screw is immediately reflected as a pitch error in the lead screw being ground.

Errors in the master lead screw are of two types:

1. Errors created during the making of the screw.

2. Errors *subsequently introduced by changes in its temperature.*

The second type, that of subsequent temperature changes, although of the greater importance, was apparently neglected in previous attempts at precision lead screw grinding. It was thought that a temperature-controlled room, or coolant supplied at room temperature, would automatically produce accurate results. In some cases, the coolant was merely "cooled", without regard for accurate control. These stopgaps are fruitless. Frictional heat from motors and gearboxes raises the temperature of the screws sometimes as much as 20 degrees Fahrenheit, expanding 20″ of lead screw 0.0025″, an intolerable amount when dealing in "tenths". This error is transferred to the workpiece proportionally to its length.

In other words, previous attempts *neglected the one cause of lead error which,*

although the least obvious, is actually the most troublesome.

Four methods are feasible for compensating or correcting temperature errors in the master lead screw:

1. Shortening its effective lead by gearing.

2. Making the master screw short in the first place, expecting it to expand sufficiently when warmed by operating.

3. Warming the workpiece through the medium of the coolant, expecting it to shrink the proper amount when subsequently cooled to room temperature.

4. Holding both the master lead screw and the workpiece at accurately-determined constant temperatures.

Either of the first two methods can be employed to compensate for a known, fixed error, but neither accommodates *fluctuations* in temperatures.

The third and fourth methods are worth investigating, since the one permits automatically-controlled coolant temperature variations and the other *prevents* fluctuations, thereby rendering coolant variations unnecessary.

The third method appeared to have the most immediate possibilities. It evaded the necessity for temperature-controlling the entire machine, and was tried first. It was used for several years with considerable success, before proceeding to the fourth method. There are some interesting phases to the third method.

This method presupposes that the machine will regularly operate at elevated temperatures; therefore, the workpiece must also be elevated, or the *effective* pitch of the master screw reduced by gearing.

There are substantial disadvantages in attempting to elevate the temperature of the workpiece. This must be done by flowing warm, temperature-controlled coolant over the work. Since this coolant is warmer than the air in the room, coolant and air conflict with each other for control of the workpiece. It is impossible to flood the work constantly; the coolant must be shut off when inspecting the work for finish, form, and pitch diameter, and when loading or unloading. Then, too, it is necessary to wait for the screw to cool to room temperature before inspecting for lead.

These factors render unfeasible control solely by raising the temperature of the coolant. There is a distinct advantage in maintaining the coolant *near* room temperature.

It is necessary, therefore, to reduce the effective pitch of the master screw by gearing. Since this principle is not well known, a specific example is appropriate. The thread grinder used is a standard Jones and Lamson 12″ x 45″ machine, with an 8-pitch screw. The ratio between the lead screw and spindle is controlled by a train of four gears, whose numbers of teeth may be represented by the symbols A, B,

C, and D. The formula for workpiece lead is:

$$\text{Lead} = \frac{2}{5} \times \text{change gear ratio, or}$$

$$\text{Lead} = \frac{2}{5} \times \frac{A}{B} \times \frac{C}{D}$$

The theoretical gear ratio for 8 threads per inch is:

$$\text{Lead} = \frac{2}{5} \times \frac{40}{80} \times \frac{60}{96} = \frac{1}{8} = .1250000''$$

Suggested gear combinations to shorten the lead are:

1. $\text{Lead} = \frac{2}{5} \times \frac{63}{50} \times \frac{31}{125} = .12499200''$ per turn or $.999936''$ per 8 turns.

2. $\text{Lead} = \frac{2}{5} \times \frac{26}{63} \times \frac{53}{70}$, or $.999909270''$ per 8 turns.

3. $\text{Lead} = \frac{2}{5} \times \frac{30}{97} \times \frac{98}{97}$, or $.99989371''$ per 8 turns.

Manipulations of the change gears can, therefore, effect minute differences in lead, bringing the effective lead of the master screw nearly correct at any required temperature. Coolant can be supplied, therefore, practically at room temperature, with an automatic control to maintain a certain differential between the coolant and the master screw.

To this end, an electronic thermostat, Fig. 69, was employed. This constantly measures the temperatures of the machine base and of the coolant, Figs. 70 and 71. Fluctuations in the temperature of the base automatically raise or lower the coolant temperature, as required.

This method of permitting the master lead screw to warm up and compensate for its fluctuations through the medium of the coolant has operated for a number of years, and with a fair degree of success. It has some limitations, however. The system is not operable until the machine has run long enough to warm the master

Fig. 69 — Electronic thermostat correlates responses of two resistance thermometers, holding coolant at predetermined temperature differential with respect to master screw.

Fig. 70 — Coolant supplied to thread grinder is filtered to eliminate danger of scratching workpiece. Arrow shows location of resistance thermometer in coolant line at end of heat exchanger.

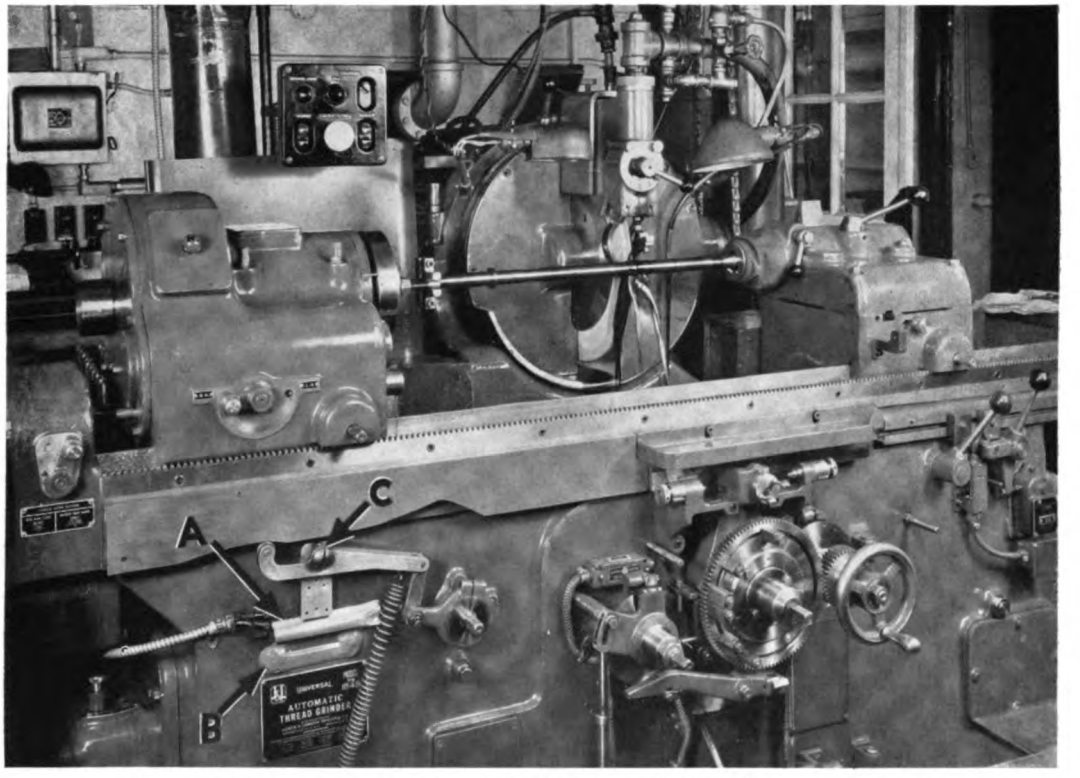


Fig. 71 — Resistance thermometer attached to base of thread grinder (A) measures temperatures of master lead screw with sufficient accuracy, since screw is entirely enclosed in base of machine. Visual thermometer (B) is for convenience of operator and not a part of automatic control. Also shows arrangement for compensating aperiodic errors in master screws. Rotation of master nut is achieved by linkage and lever against serrated cam plate (C).

screw approximately 20 degrees. Stopping the machine, and small deviations of the coolant from room temperature detract from top performance.

It was decided, therefore, to proceed to the fourth method, eliminating temperature changes. The machine base, accordingly, is flooded generously with constant-temperature lubricating oil, fed from large jets directly upon the master screw, thence down over the transmission and back into the reservoir in the base. The oil in the base is continuously circulated through a water-cooled heat exchanger, holding it constantly at room temperature. In addition, of course, proper temperature control over the coolant must be maintained.

Various other temperature considerations affect the lead of the workpiece, most of them revolving around the action of the grinding wheel. Rough grinding, with its attendant high rate of stock removal, heats the work much faster than finish grinding, where only a few "tenths" are removed. During roughing, therefore, the coolant must be supplied at a lower temperature to absorb this excess heat. During finish grinding, every precaution must be taken

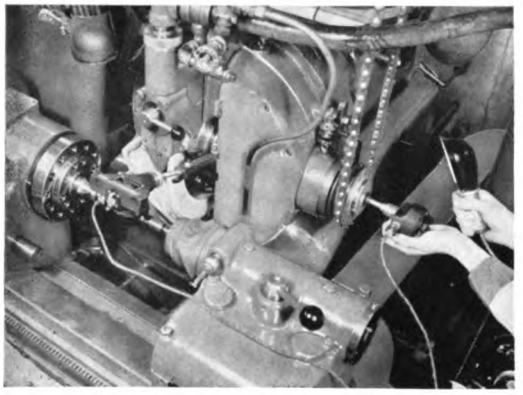


Fig. 72 — Dynamic balance of thread grinding wheels is accomplished with Davey Vibroscope. Stroboscope (right), flashed synchronously with rotation, indicates direction and amount of unbalance. Balancing weights are shown in wheel-holding flange. To make test sensitive enough to register a readable amount, spindle housing floats in springs during this operation.

to maintain the coolant within ± 1 degree of the proper temperature. The dead center end must be flooded generously, to prevent friction from warming up the last two or three inches.

The wheel dressing diamond must be sharp to assure clean grinding. Wheels dressed with dull diamonds glaze and fill quickly, heating the work, resulting in short and non-uniform leads. Diamond maintenance entails considerable expense, since they cannot be used after they are worn to flats of .005″ or .006″.

Dynamic Balancing — Grinding wheels and all rotating parts of the machine must be dynamically balanced, not only to prevent chattery finishes, but also to eliminate an obscure thermal effect. If the wheel does not balance, most of the work load is carried by a small portion of the wheel, which soon becomes dull and glazed, resulting in heating, which, in turn, results in short, non-uniform leads.

Static balancing of the grinding wheel is not sufficiently accurate. It must be balanced dynamically, under actual operating conditions, with the coolant actually flowing on it. A vibrometer with a stroboscopic phasing device, Fig. 72, achieves this. The vibrometer is held between the work centers of the machine, its contact touching an arm attached to the spindle housing. To make the test as sensitive as possible, the spindle housing floats on springs for this operation, then is rigidly fastened to the heavy wheel slide for grinding.

The wheel driving motor is also fully dynamically balanced. A special motor is employed for this, with shaft extensions at both ends, Fig. 73. Balancing weights in the pulley and in the flange in the opposite end can be adjusted at any time, to compensate for changes which appear inevitably to occur within the motor.

Fig. 73 — Importance of dynamic balancing of thread grinder parts is further emphasized here. Both ends of motor shaft have balancing weights. Periodic checking is advised since armature windings are somewhat unstable.

Compensating Aperiodic Errors — In addition to the various thermal errors described, there is another type, previously mentioned but not discussed. This is the error generated in the manufacture of the master screw, usually non-uniform, called aperiodic, corrected in the following manner:

The standard thread grinder is equipped with a "pickup" adjustment to shift the workpiece axially while rotating. This is necessary to pick up a thread previously roughed, or partly ground. A worm geared shaft, shown in Fig. 71, accomplishes this by rotating the master nut. Adapted to this is a linkage, lever and a roller, following a cam plate, cut to suit the aperiodic errors in the master screw.

Checking of Lead Screws — Since so many types of error must be compensated, rapidly operated checking equipment is necessary. Operating conditions must be checked and corrected constantly. Each screw must be checked *immediately* after grinding. It is partly for this reason that the fourth grinding method, i.e., that of holding all parts constantly at room temperature has been adopted. Inspection of the screws embodies four phases:

1. Finish, usually inspected visually during grinding.

2. Pitch diameter, checked in conventional ways, with thread micrometers or over wires.

3. Form, checked with a specially-built bench center, Fig. 74, upon which is

Fig. 74 — Thread form checking instrument, showing template gage inserted into thread. Plane of sighting edges of template is parallel with axis of workpiece, eliminating necessity of calculating helix angle or change in thread angle due to helix angle.

mounted a microscope and a slide for holding form templates. The sighting edges of the templates are held in the same plane with the center line of the screw, and in the focal plane of the microscope. This

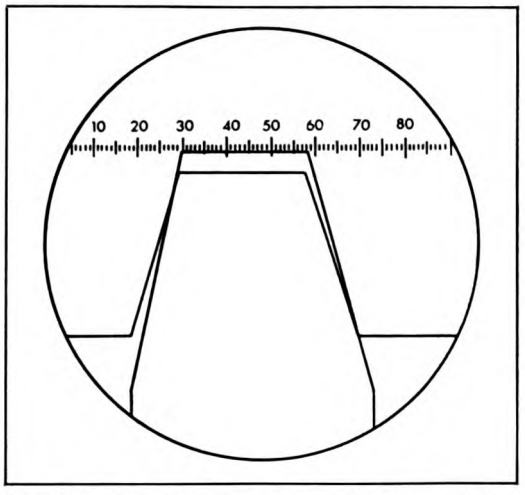


Fig. 75 — View through microscope, showing method of determining necessary corrections by comparison with template gage. Graduations on microscope reticle show correction required.

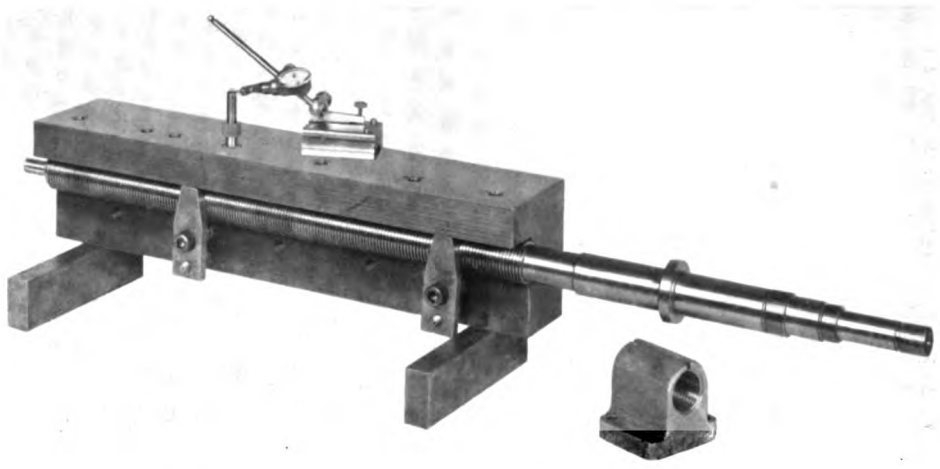


Fig. 76 — Fixture for checking lead of Moore Jig Borer lead screw.

eliminates corrective computations for helix and thread angles; templates are made to nominal axial thread dimensions. Comparisons of thread form against the templates are made with the microscope. Graduations of .001″ on the reticle assist the operator in estimating the required correction, Fig. 75. Adjustments are made on the wheel-trueing device until the template "shuts out light" in the thread.

4. Pitch, or lead, must also be checked rapidly and accurately. Fig. 76 shows a device for this, and Fig. 77 a schematic view of its use. The workpiece is clamped into a Vee, and a tapered pin, inserted through the holes, is brought against one flank of the thread. Indicator readings of the height of the pin above the platen of the fixture are interpreted as measurements of lead.

Characteristics of this fixture are sensitivity and accuracy of a high degree. A steep-sided Acme thread, for example, magnifies lead errors approximately four times. Close proximity of all parts promotes rigidity. Although not universal, or

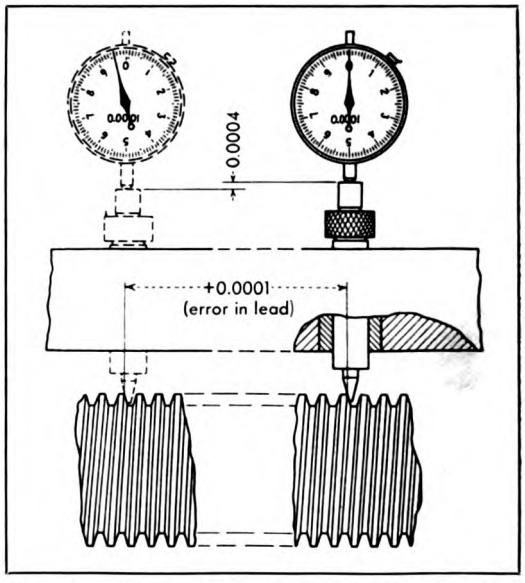


Fig. 77 — Exaggerated schematic view, illustrating checking principle employed in fixture shown in Fig. 76. Right hand indicator shows pin to stand .0004″ higher than when in left hand position. With 29 degree Acme thread, lead of screw between these two holes is therefore .0001″ too long. Errors are minimized by using same *pin and* same *indicator setting for both positions.*

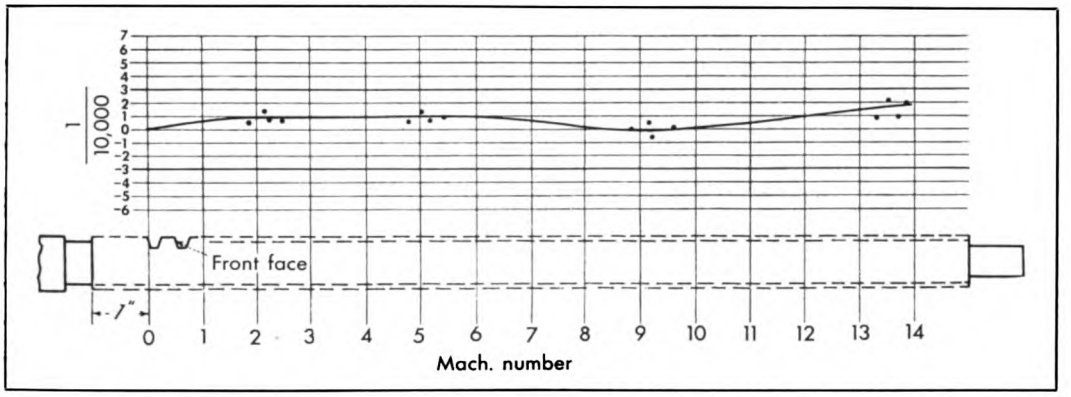


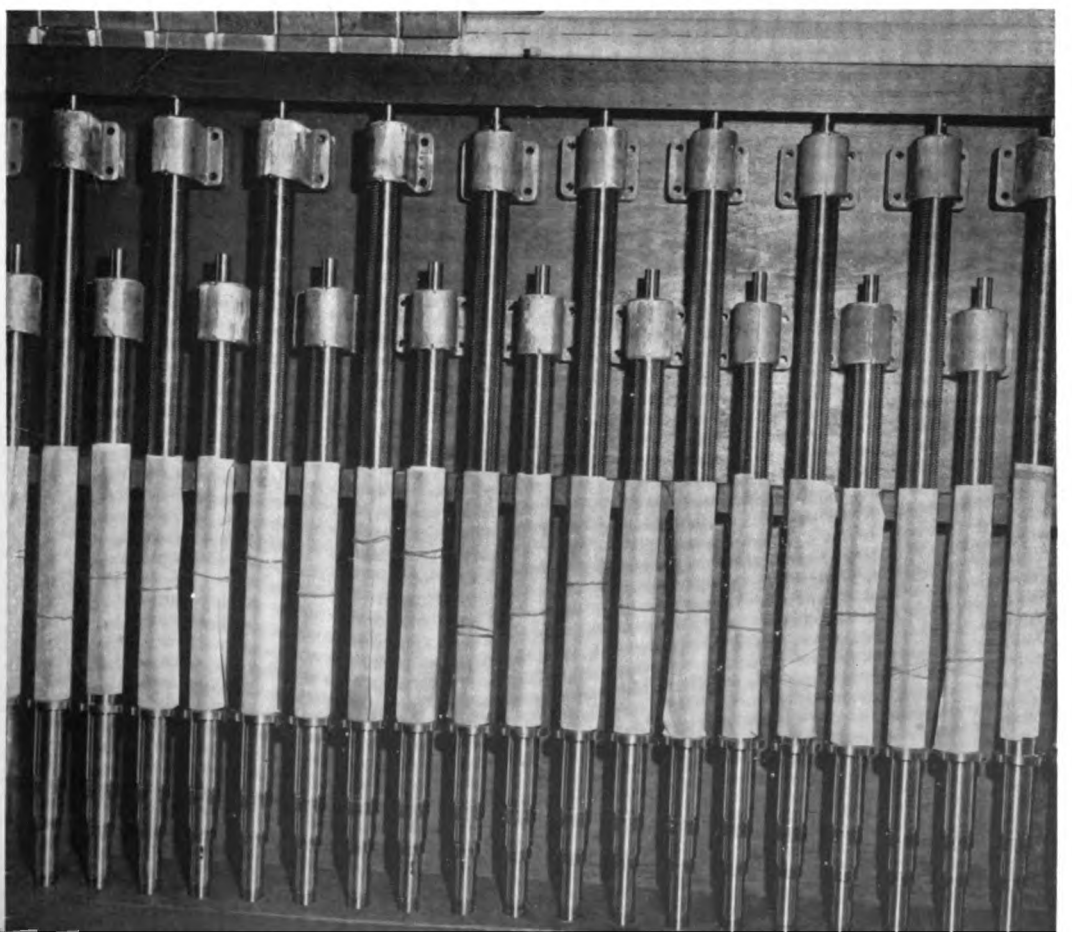
Fig. 78 — Typical graph of errors as plotted for each lead screw. Average errors of large number of these graphs are basis for cutting serrations in compensator cam plate, Fig. 71.

flexible for various kinds of work, it is extremely rapid for the particular job for which it is designed.

This speed of checking is of great importance in maintaining control over grinding conditions. A graph of errors of each screw is charted, used as a basis for any necessary adjustments and filed for future reference, Figs. 78 and 79.

The combination of thread forms em-

Fig. 79 — Batch of lead screws, finish-ground, fitted to nuts, in storage rack. Blueprint wrapped around each screw is chart of errors, Fig. 78.



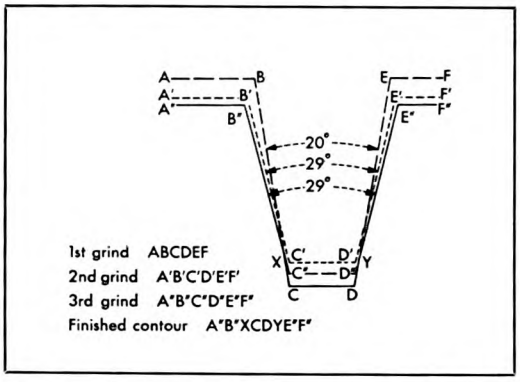


Fig. 80 — Typical thread forms produced in rough and finish grinding stages. Grinding wheel is not allowed to touch root of thread while finish grinding. Thread side has a break at X and Y.

ployed provides an interesting sidelight to the grinding of these screws, Fig. 80. Roughing and finishing are carried out, not as one continuous operation, but three. The screw is first ground to a 20° form, and somewhat deeper than the nominal thread depth. Re-roughing brings the thread to the 29° angle, but not to full width or depth. Final grinding is done with the wheel dressed to a form which will go slightly past nominal depth, but not to the depth of the first rough grinding. Danger of grinding a "step" in the bottom of the thread is eliminated, yet the wheel is not permitted to touch the bottom during finish grinding.

Between all successive operations, screws are artificially aged to prevent subsequent dimensional changes (see pages 92 and 93).

Final Checking of Lead Screws — Accurate manufacture of the screws is no complete guarantee within itself that accurate table movement will result. Inaccurate mounting or misalignment of the nut can result in inaccurate table movement as well. For this reason final checking of lead accuracy is always done with the screw and nut assembled under actual operating conditions.

Final checking is done with gage blocks or step gages, Figs. 81 and 82. Standard

Fig. 81 — Checking lead screw, nut and table assembly. Gage blocks, although not used during operation of Moore Jig Borer, are final proof of accuracy. Special gage blocks, accurately ground to permit them to be wrung together lying down, are used for this.

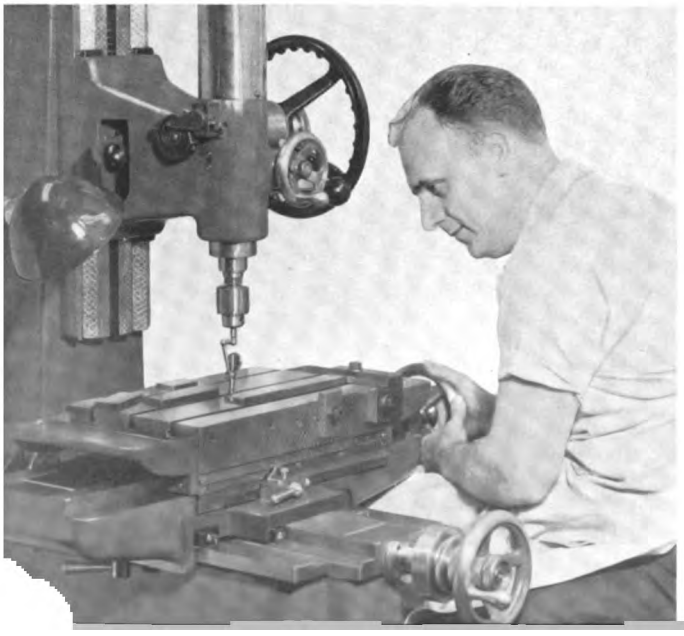


Fig. 82 — Difficulty of maintaining high accuracy of gage blocks has led to development of these "step gages". They may be re-conditioned at any time by lapping steps. Made in one piece and thoroughly stabilized, they are ground and lapped to gage block precision.

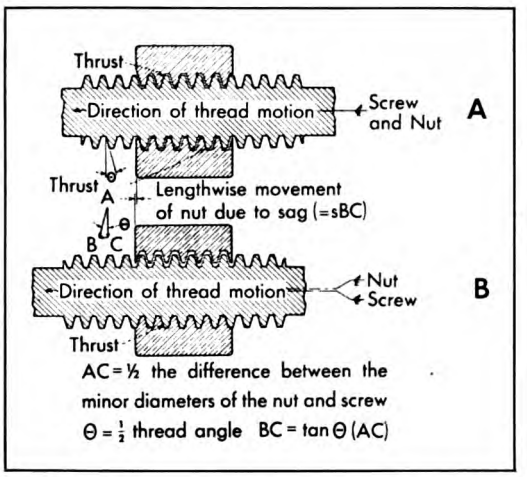


Fig. 83 — (A) Screw perfectly aligned with nut. Entire front face of screw is in contact with nut. In this condition forward movement of nut follows lead screw. (B) Effect of improper alignment. "Sag" causes nut to move forward from normal position and results in inaccuracy. Blame for this is often incorrectly placed on screw itself, instead of misalignment.

gage blocks are not usually made with a view to holding the sides perpendicular to the gaging surfaces, hence will not wring together when lying on the table. The difficulty of maintaining these blocks has led to the making of the step gages, which are easily re-conditioned.

Apparent lead errors, attributable to misalignment, raise these questions:

How does misalignment affect lead?

How can misalignment be prevented?

If misalignment cannot be prevented, can the thread form be modified to minimize its effect without jeopardizing manufacturability?

Fig. 83 describes the effect of misalignment on lead.

In sketch B, as contrasted with A, the screw "sags", or is laterally displaced from the center of the nut, and pushes the nut past its normal position indicated by "lengthwise movement", an amount proportional to the tangent of the thread angle plus an amount proportional to the tangent of the helix angle.

Alignment of the screw, and elimination of the "sag" and its accompanying lead error can be maintained in several ways, each with its advantages and disadvantages:

1. By supporting the screw on a tight-fitting pitch diameter. This is disadvantageous, not only because of the difficulty in manufacture, but if attained, results in a wedging action between screw and nut, creating heavy friction and a high wear rate. The screw eventually becomes loose, defeating the purpose of this method.

2. By supporting the screw on a loose-fitting pitch diameter, depending upon axial pressure between the screw and nut for centralization. This method is satisfactory only for heavy loads, such as the thread grinder table, Fig. 68. It is not suitable for a light jig borer.

3. By supporting the screw on its major or minor diameter in the nut. One disadvantage is the difficulty of producing a screw having perfect concentricity between its pitch circle and its other diameters. Eccentricity here would result in apparent lead errors. Dirt and burrs, sure to get into the corners of the screw and nut, promote wear and impair accuracy.

4. By supporting the screw in journals, concentric with the pitch circle. Although too expensive for all but high precision

Fig. 84 — Checking alignment of lead screw in nut at assembly. Height of screw from bearing ways on saddle must be equal to height from ways on base of machine. Precision gage blocks transfer measurement to screw.

jobs, it has proven the most satisfactory for applications such as the Moore Jig Borer.

The effect of lead errors from misalignment may be lessened by variations in thread form. As previously pointed out, both the thread angle and helix angle contribute to the error, the thread angle the most. It might, therefore, seem that a square thread would eliminate most of the trouble.

This theory has limitations, however. Not only is it the most difficult to produce, but it must be aligned by the most expensive method, that of the two journals at the ends of the screw. Any misalignment means one-sided contact, promoting rapid wear.

The reasonable compromise is that of the Acme thread, supported by journals, and is the design adopted for the Moore Jig Borer and Moore Jig Grinder. The flanks are steep, minimizing the effect of misalignment, yet much less difficult to manufacture than the square or buttress thread.

Fig. 84 exemplifies the necessary precautions to assure good alignment. Measurements are taken from all sliding ways with gage blocks, transferred to the screw

with indicators, resulting in alignment within .0002″ to .0003″.

The foregoing discussion of measuring methods and lead screw grinding may not be considered by the reader to be pertinent to the problem of locating holes. It was felt by the author that it might be interesting, and is representative of the many refinements necessary to attain high accuracies.

Locational Control and Long Life — An accurate measuring system is, in itself, no guarantee of overall locational accuracy. The space within the capacity of the Jig Borer is three-dimensional, and all movements within it must be perpendicular, or parallel, as the case may be, within close limits. The measuring system controls the distance moved in only one direction at a time, and cannot compensate for errors from other sources. The error between any two holes bored is the total of many different errors, all superimposed upon each other. Each possible source must be carefully scrutinized, both in design and construction. Otherwise, any measuring system, however accurate in itself, is fruitless.

Further, the measuring system accounts for only a *small part* of the total error. Added to it are errors from these possible sources:

1. Out-of-squareness or out-of-parallelness.

2. Relative movement of machine parts due to loose fits or poor bearing surfaces.

3. Movements of parts due to clamping or locking devices.

4. Spring due to cutting pressures.

5. Thermal expansion.

6. Aging changes.

7. Wear.

8. Effective magnification of any of the above errors, such as might be brought about from centrifugal displacement or vibration, as in a lathe, or operating at a remote distance from bearing surfaces, as in a milling machine, Fig. 91.

Many of the above errors are commonly regarded purely as functions of workmanship and inspection. This is not necessarily the case. Proper design is a large factor, both in assisting the workman to achieve the required initial accuracy, and in minimizing the effect of the inevitable subsequent wear.

A point-by-point analysis emphasizes the futility of merely installing a measuring system, however accurate, on a conventional machine, if the fundamental design does not provide a suitable foundation on which to build the required accuracy.

1. Squareness and Parallelism — Attainment of perpendicularity and parallelism to the same high degree of accuracy required in a Jig Borer is unnecessary in machines for most other purposes, such as lathes, grinders, milling machines or shapers. A lathe, for example, is largely unidirectional; spindle, axis, tailstock and

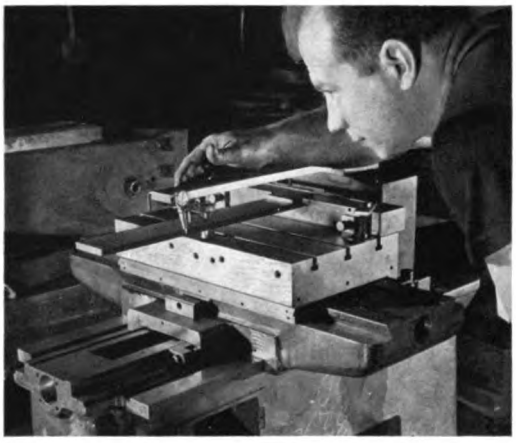


Fig. 85 — Checking perpendicularity of cross slide. Base of master square is indicated parallel to table travel. Blade of square is then indicated to detect errors. Test is self-checking; reversal of square proves its accuracy.

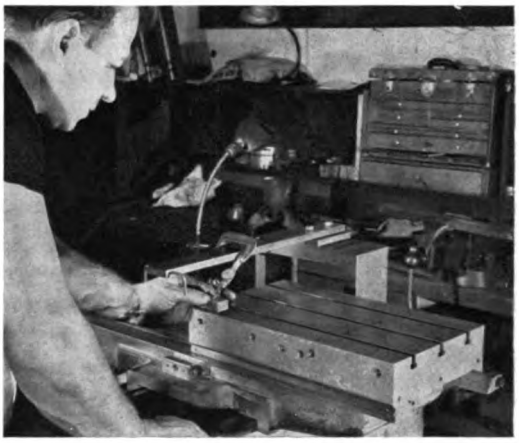


Fig. 86 — Checking parallelism of table top with travel. Design of all parts provides grinding ways longer than distances traveled. Wide base minimizes sag of table, of special importance in jig borers. See also Fig. 91.

carriage travel must be parallel. Cross travel need not be accurate over long distances, and there is no vertical travel at all. Grinders, like lathes, are largely unidirectional. Milling machine users do not usually expect the cross, vertical and table travel to be perpendicular any closer than the nearest "thousandth", or thereabouts (see also Fig. 55). In a shaper, it is merely necessary that the ram and cross travel be parallel with the table top. This is easily achieved by taking a cut over the top of the table after assembly.

A Jig Borer, however, must be true in *every* direction, so that hole spacings on diagonal lines, either in horizontal or vertical planes, will be accurately measured. For this reason, surfaces of all sliding ways are hand scraped, and cannot, at present, be finished accurately enough by grinding or other methods. The attainment of initial high accuracies is achieved by careful workmanship. Long life is assured by making all sliding ways long, so that the effects from looseness developed from wear will be minimized. The care required in scraping and checking bearing surfaces of the base, cross-slide, and table are exemplified by Figs. 85 and 86.

Attainment of high accuracy of alignment of the spindle, quill, and quill housing assembly presents a complex problem. It is commonly thought that tramming the Jig Borer table with an indicator held in the spindle is a conclusive test of alignment. Actually, the error shown in this manner is the total of six different errors, *each* of which must be checked individually:

a. Parallelism, table top to base. This effect, while slight in thin, flat pieces, is considerable in deep box jigs, both as to position and squareness of hole to face of work, and is doubled on rotary table work.

Fig. 87 — Checking perpendicularity of column ways with table top. Sensitivity of test is increased by using fixture, permitting longer travel than would be possible with quill housing. This test, like Fig. 85, is self-checking by reversal.

Fig. 88 — Checking parallelism of quill travel with column ways. Two indicator readings, one with housing raised, quill extended, other with housing lowered, quill retracted, must agree true. Sensitivity of test is high, due to doubling effect of rotating indicator in hole.

Table top must be parallel, therefore, to direction of travel in both directions.

b. Perpendicularity of column ways with table, Fig. 87.

c. Fit of quill housing in column ways. Important because it determines the ability to repeat spindle axis positions when vertical adjustments are made.

d. Parallelness of quill with column ways, Fig. 88.

e. Curvature of quill. A treacherous fault, since seldom recognized. Results in quill traveling in a curved path. To discover this, the quill is rotated in its bushings and indicated, Fig. 89. For this reason, the rack in the Moore Jig Borer quill is set in, so the entire quill may be rotated to be sure it is straight, not deformed from heat treating, grinding or lapping.

f. Parallelism of axis of spindle rotation and quill travel. This can only be checked by using indicator holders of different lengths, to exaggerate the relative positions of different axis extensions. This would not be important *if* the same extension could always be employed for indicator and boring tool. This condition cannot always be met, however. The checking or boring of deep holes in box jigs, frequently requires different lengths of indicator holders and boring bars. Accurate alignment of spindle axis and quill travel are of paramount importance.

The futility of checking spindle alignment by tramming the table is shown by the above analysis. The table might tram perfectly if two or three errors compensate each other, without any assurance that the Jig Borer is accurate. *Each* possible error should be investigated before the machine is accepted or condemned on the basis of a check by table tramming, Fig. 90.

2. Relative Movement of Machine Parts

Fig. 89 — Jig Borer quill, regardless of difficulty of manufacturing, must be straight and true. Setting rack below surface in Moore Jig Borer permits rotating it to check curvature.

Fig. 90 — Tramming table from spindle shows total *of six component errors but is not conclusive test of correctness. Errors found are subject to careful analysis to insure correcting proper component.*

Due to Loose Fits or Poor Bearing Surfaces — Loose spindles and gibs have probably spoiled more hole-locating jobs than all other causes put together. Remedies for this, especially in high-precision machines, such as Jig Borers, call forth the designer's utmost ingenuity. The designer cannot prevent wear from taking place, but he can minimize its effect, by consideration of the following points:

a. All slide-ways should be as close to the workpiece as possible.

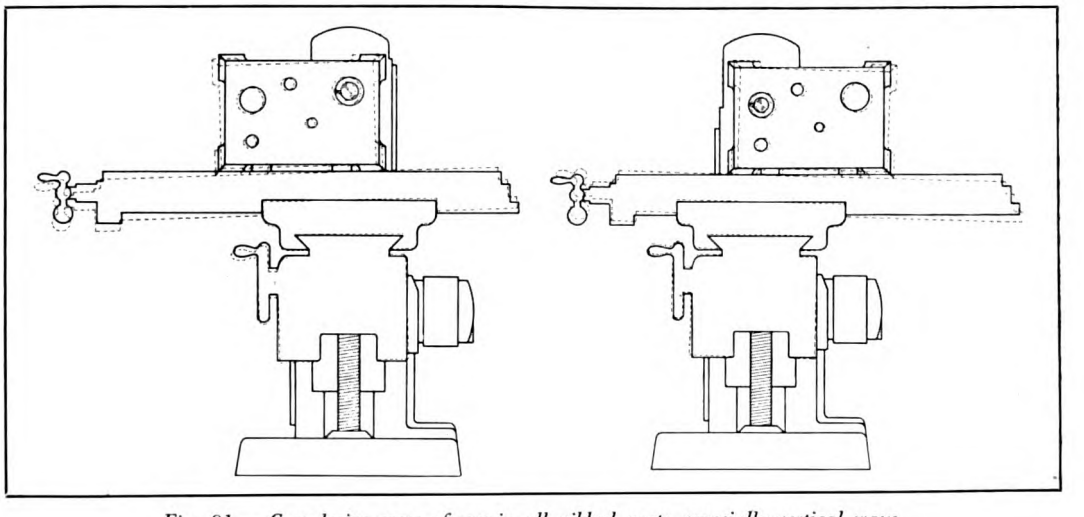


Fig. 91 — Cumulative error of sag in all gibbed parts, especially vertical ways.

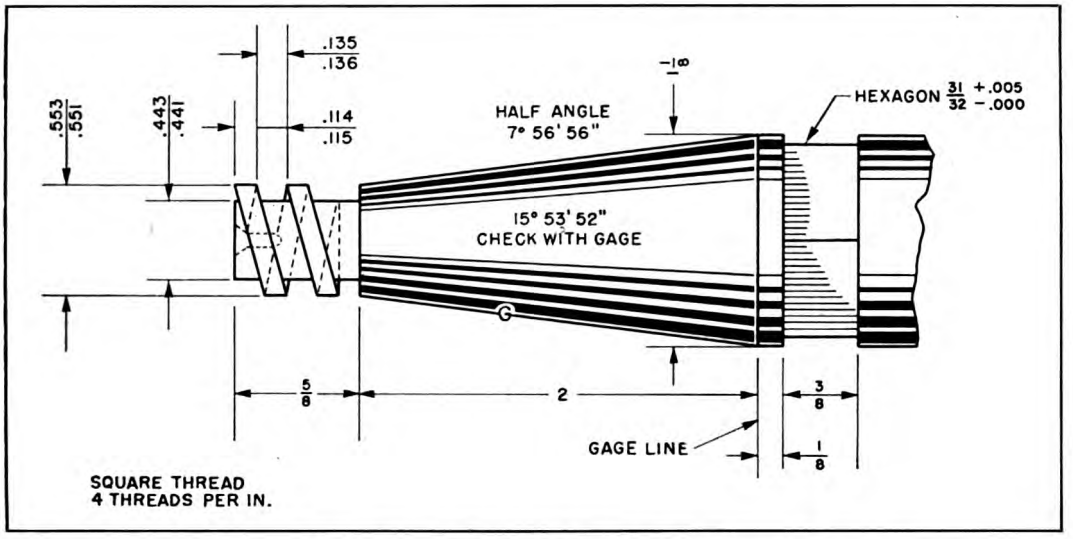


Fig. 92 — Nominal dimensions, special taper shank for Moore Jig Borer.

b. Avoid vertical movement of heavy parts, such as the knee, saddle, and table in the conventional milling machine. Not only is the sag from table weight exaggerated, Fig. 91, but great force is required to clamp the knee to the machine column, (see also Figs. 94 and 95). In the Moore Jig Borer, the only vertical movements apply to parts of comparatively light weight, namely, the quill, and quill housing. The quill housing is not gibbed to the column, but is clamped directly into prismatic Vee ways. To prevent the entrance of dirt between the ways, a heavy spring holds the housing into the ways even when not locked.

c. Wear-resistant materials capable of receiving high finishes. All castings should be close-grained semi-steel. In the Moore Jig Borer, they contain nickel to promote further fineness of grain. Scratching and roughness are thereby eliminated, and all bearing surfaces are scraped to long-lived, intimate, rigid contact. Sliding steel parts, such as the quill and its guide bushings, are made from hardened steel and ground and lapped to a high finish and plug gage fit.

d. Spindle and quill. As above mentioned, the plug gage fit and high finish imparted to the quill and quill bushings eliminate sideways movement. In addition, the spindle is mounted on preloaded ball bearings in the quill, preventing movement between these parts. Spring, or deflection under load, is possible, of course, see page 66. Sideways movement due to oil film, as in the old-style plain bearings, however, is eliminated.

To attain maximum rigidity, all cutting tools must make perfect contact with the spindle nose. To provide the greatest ease in inserting tools, to permit easy cleaning,

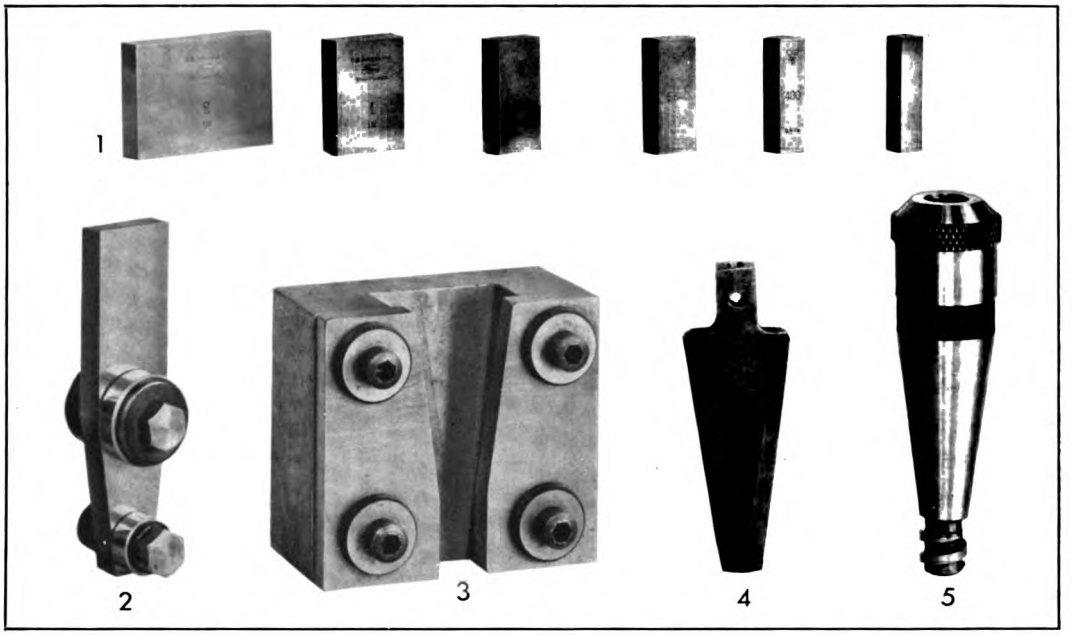


Fig. 93 — Gaging equipment to assure strict interchangeability of all cutting tools and spindle noses. Square thread lock, developed especially for Moore Jig Borer, eliminates drawbar through spindle.

1. Special gage blocks are foundation for entire system, used for no other purpose.

2. Diameters and positions of hardened chrome-plated buttons on master gage are periodically checked against blocks.

3. Correct taper in adjustable V gage is achieved by inserting master gage and correcting until buttons contact V gage equally.

4. Arrow-headed gage is ground to the taper in the V gage. Infinitely more sensitive than conventional round plug and ring taper gages because of its tangential effect. Arrow-head gage is used to check taper in spindle nose.

5. All taper shank tools such as collet shown, being ground to V gage, are strictly interchangeable. The sensitiveness of method is estimated to be ±.000025".

and to avoid the use of a drawbar through the spindle, a special shank was designed to hold cutting tools in the Moore Jig Borer, Fig. 92. The square thread on the upper end of the shank pulls it up into the spindle against the taper. Gaging, especially of the taper, presents an interesting problem. The conventional ring and plug-gages, lacking sufficient sensitivity, the elaborate set of taper gages shown in Fig. 93 was evolved. Extremely sensitive, these gages assure strict interchangeability between all spindle noses and shank-mounted tools.

e. Centralization of measuring system in *guiding ways.* Looseness of ways from their inevitable wear tends to permit sideways, twisting, or snakelike movement. To prevent this, movement should be imparted and measurements should be taken along a line in the center of the ways. The lead screw, in this respect, presents a further advantage not usually found with other types of measuring devices.

3. Movement of Machine Parts Due to Locking or Clamping Devices — Machines not specifically designed for Jig Boring are not customarily equipped with

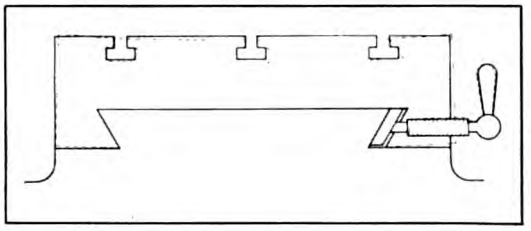


Fig. 94 — Clamping against gibs, although conventional practice in many machines, is inadequate for jig borers. Table movement resulting from this practice, due to spring in all parts, can amount to as much as .001".

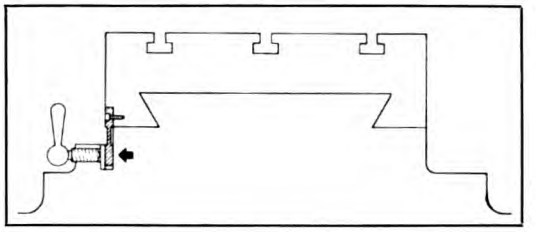


Fig. 95 — Special clamp bar, attached to table of Moore Jig Borer, prevents movement of table from clamping. Bar is rigid endwise, but sufficiently flexible that crosswise pressure for clamping will not influence table position.

non-influencing locking and clamping devices. For example, Fig. 94 shows a typical milling machine table clamp, operated by means of a pressure screw on the gib, and the attendant dangers. Although parts may be closely fitted, clamping cannot be achieved without the exertion of considerable force. This springs all the parts, resulting in sideways movement of the table.

In the Moore Jig Borer, only three movements require locking: the cross slide or saddle, the table, and the quill housing. The cross slide is clamped by pulling directly down on the shelf extending from the base. The quill housing, as previously explained, is pulled back into a pair of Vee ways, and the table, to avoid clamping against the gib, is locked by a special clamp bar, running along the full length of the table, and rigid endwise, but free to flex in a crosswise direction, Fig. 95.

4. Spring Due to Cutting Pressures — Any cutting tool, to cut, must have pressure applied to it, deforming both the work and machine members. Any structure, however massive, is deflected by any force, however small. The minutest cutting pressure causes a certain amount of deflection, in direct proportion to the required cutting pressure, and inversely as the stiffness of the structure. The stiffness of the structure depends upon its size, sections and the moduli of elasticity of the materials comprising it.

It might, at first glance, appear that rigidity would be of far greater importance in heavy machines, intended for roughing, than in high-precision machines, where the finishing cuts are always light. Other conditions being equal, total deformations produced by heavy cuts are, of course, greater. On the other hand, small deformations are large in proportion to the close tolerances expected from high-precision machines, and their effect upon accuracy is relatively just as great.

Internal grinding provides a typical example. Although the cuts taken may be light, the high rotative speeds of the grinding spindle demand light, delicate parts and bearings. Deflection within these parts necessitates "sparking out" when finish grinding, to produce a true, straight hole.

The cutting-pressure spring problem can be largely eliminated by making all stress-bearing parts massive and heavy, although obviously unsatisfactory because the addition of weight inconveniences the operator.

A compromise must be found by properly proportioning of all parts, and by employing materials with high elastic moduli.

The main body, consisting of base and column, not frequently moved around, may be substantial, and presents no difficult problem. The spindle, quill, and quill housing, however, are frequently moved, and it is here that the most favorable compromise between rigidity and lightness is necessary. Partly for this reason, the quill and its guiding bushings, pressed into the quill housing, are made from hardened steel, and fitted like plug gages. The internal design of the spindle and bearings is also such as to promote the greatest possible rigidity in proportion to weight.

Since cutting pressure springs the workpiece, as well as the machine parts, considerable care must be exercised in the manner of clamping odd-shaped workpieces to the table. See also Jig Boring Practices, Chapter V.

5. Thermal Expansion — One of the most treacherous causes of dimensional instability is thermal expansion. Toolmakers know that increases in temperature cause dimensional increases. They cannot take them fully into account on any particular job, however, because of the many

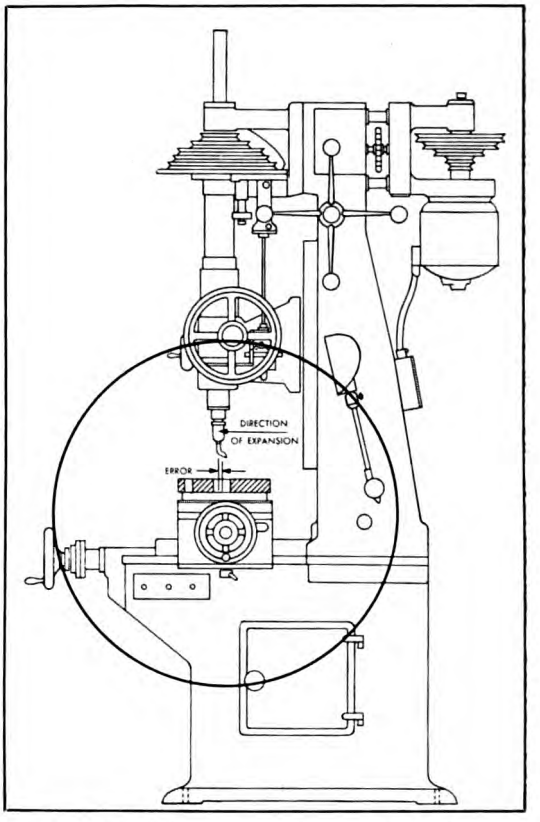


Fig. 96 — Thermal expansion of quill housing.

places in which the expansion occurs, and the complexity of the job of figuring out the resultant total effect. Nor should they be required to do so.

The design of the machine should automatically take into account as many of the effects as reasonably possible, and thereby relieve the user of this headache.

There are three major sources of temperature change:

1. Warming up of spindle and spindle housing due to friction of spindle bearings. The effect of this is to displace the spindle outward, away from the supporting column, Fig. 96.

2. Warming up of the workpiece due to action of cutting tool, especially during roughing cuts. The effect of this is to make all the holes in the workpiece too close together, because of the subsequent shrinking when the piece is cooled to room temperature.

3. Room temperature changes. This condition is at its worst when starting a job on a cold machine after a night or week-end in cold weather, with the heat turned off, and finishing it a few hours later after the room is considerably warmer. The effect from this would be self-compensating if all parts of the machine and the workpiece warmed at the same rate. Unfortunately, they do not. The light exposed parts warm up first, and the heavy, massive parts warm last. The exact rates of temperature increase are not known, and the mechanic cannot possibly estimate their effect with any degree of accuracy. Exposed measuring devices, such as gage blocks or end measures, are especially subject to this effect.

All these effects are superimposed upon each other, and it is small wonder that the workman is completely baffled when he tries to understand why the job went wrong.

Since thermal expansion occurs in practically all materials, it might seem that there is very little the machine manufacturer can do about it, and that he might as well throw the problem in the lap of the user and forget it. Moore engineers have taken the view that it is the responsibility of the manufacturer to attempt to solve the problem for him, and have made definite contributions in this direction.

The most rapid variation, as far as the machine itself is concerned, takes place in the spindle housing. Any type of spindle bearings, even the so-called anti-friction bearings, generates a certain amount of heat, expanding the spindle housing. This continues for two or three hours, until the housing gets warm enough to create an equilibrium between the heat generated by the bearings and that dissipated into the air from the housing. When this point is reached, no further expansion takes place. However, if the machine is stopped for a time, heat dissipation continues, and the housing shrinks again. Attempts have been made to control this by means of heaters and thermostats, but these are not entirely satisfactory because of the difficulty of exact control and of applying the heat in the same place as that applied by the bearings. Cooling by water-jacketing produces a cumbersome arrangement, especially in a high-precision machine where inconvenience and accessibility are major requirements.

The logical solution, of course, is to stop the expansion at its source by using a material of low expansion index. Main spindle housings in all Moore Jig Borers and Jig Grinders are made from Invar cast iron, a 36% nickel alloy. Although far

more expensive than cast iron or semi-steel, use of this low-expansion material adds 25% to the overall value of the machines by reducing the importance of warming-up periods.

The remaining two difficulties, warming up from cutting and room temperature changes, are reduced by employing lead screws as a measuring device.

Inasmuch as they are entirely enclosed within the body of the machine, they follow it very closely in temperature changes. The effect on the measuring system from room-temperature changes is minimized.

The temperature compensating effect of the lead screw principle is far more important in another, less obvious manner, in connection with workpiece temperature.

It is of great importance that the finishing cuts all be taken when the workpiece is as nearly as possible at room temperature. It is also important that they be made during as short a period of time as possible, to give room temperatures and spindle temperatures the least possible opportunity to change. All roughing, therefore, on a certain piece of work should be completed before any finishing operation is attempted. The Jig Borer should be designed to promote this.

If the measuring device is slow, tedious and cumbersome, there will be a tendency for the operator to short-cut the best practice and rough and finish each hole completely before proceeding to the next hole. The workpiece, therefore, will be too warm for finish boring. The locations of holes bored in this condition will subsequently change due to thermal shrinkage.

The operator should be given every possible incentive, therefore, to rough *all* holes in a certain piece *before* finish-boring *any* of them. The use of lead screws provides such an incentive. Table settings can be made faster than tools can be changed. The operator does not hesitate to follow the correct procedure. In addition to errors due to the increase in temperature of the workpiece, there is always the possibility that some part of the setup has slipped or shifted during the roughing, and that the quill housing has warmed enough to disturb the setting. After roughing, the original setup may be checked and reset, if necessary, before taking any finish cuts. This gives double assurance that the finish boring is done under the best possible conditions.

The idea of working accurately *in spite of* lead screws is a misleading understatement. We can work more accurately *because* of lead screws — their great speed and convenience is definite assurance that the finish boring will all be done within a short enough period of time to maintain the most uniform and favorable conditions.

6. Stablization of Materials — Dimensional instability of hardened steel has long been recognized as a problem, but only recently has it been given a measure

of the attention it deserves. As a result of the increasing demand for higher accuracy standards in machine tools, gages, etc., considerable research has been conducted on the subject.

Conclusive evidence proves that much of the skill and workmanship expended in achieving high accuracy in hardened steel parts may be nullified by instability of the material itself. This instability may manifest itself in any one, or any combination of three forms:

a. Crystalline growth, resulting from a gradual decomposition of unstable austenite retained at room temperature after quenching.

b. Shrinking, resulting from a partial decomposition of raw or untempered martensite.

c. Distortion due to "crowding", resulting from either of the two aforementioned reactions occurring where the unstable elements are unsymmetrically distributed within the piece.

The rate and ultimate magnitude of this dimensional change, as well as its direction, are dependent on so many variables as to be virtually unpredictable.

While metallurgists are unanimous in agreeing that an effective stabilization should be included in heat treating hardened steel parts for precision applications, there is a serious disagreement as to the technique. Recently some work has been done toward alloying steels with a view toward eliminating these unstable constituents in the "as hardened" condition. Since this is not as yet an accomplished fact the problem of stabilizing the presently available steels is still of paramount importance.

Lately, considerable publicity has been given to sub-zero treatment as a stabilizing process and, properly applied, it may have some value. However, its promiscuous use is largely valueless and may actually be harmful.

With the development of the X-ray diffraction devices it is now possible to volumetrically determine the potential instability of any hardened part through a measurement of the percentage of retained austenite. Working with this device it has been proven that a high draw actually provides the most certain means of insuring stability by eliminating both of the offending constituents without any drop-off in hardness. In practice, this latter method has so far proven to be the most satisfactory both from certainty of results obtained and because no special equipment is necessary. Further study of this problem is continuously under way.

7. Wear — Wear eventually produces the same results as those caused by loose fits or poor fits and finishes, pages 85 to 88. Although wear cannot be prevented entirely, its effects may be neutralized in two ways:

a. By retarding it as much as possible.

1. Through wear-resistant materials.

2. Through highly finished, *accurately generated, not merely polished*, wear surfaces.

3. Through the generation of close fits on all mating parts, with a view to excluding wear-producing dirt.

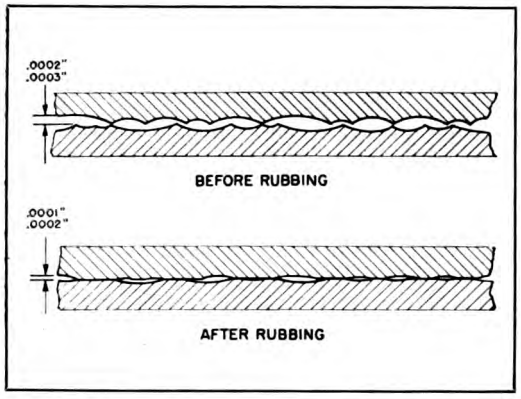


Fig. 97 — Effect of pre-wear on scraped bearing surfaces. Any scraped surface consists of a series of hills and valleys with the peaks all in the same plane. Rubbing two mating surfaces together produces flat plateaus, hard, glazed and long-wearnig.

4. Through pre-wearing of all scraped surfaces. A scraped surface, although "flat", is in reality a series of hills and valleys, the peaks of all hills being in the same plane. The peaks, however, are relatively small, and wear rapidly from use. All mating parts in the Moore Jig Borer are rubbed together with kerosene, to *deliberately* wear them, removing .0001″ to .0002″ from each surface, but producing surfaces of at least 50% or 60% of actual bearing, Fig. 97. Since the surfaces become hard and glazed, they wear from this point on very slowly, offering many years of service.

b. By minimizing its effect through compensation in design.

1. Through the use of *long* bearing surfaces, extended, if possible, far beyond the travel.

2. Through the use of non-influencing clamps and locking devices, exemplified in Figs. 94 and 95.

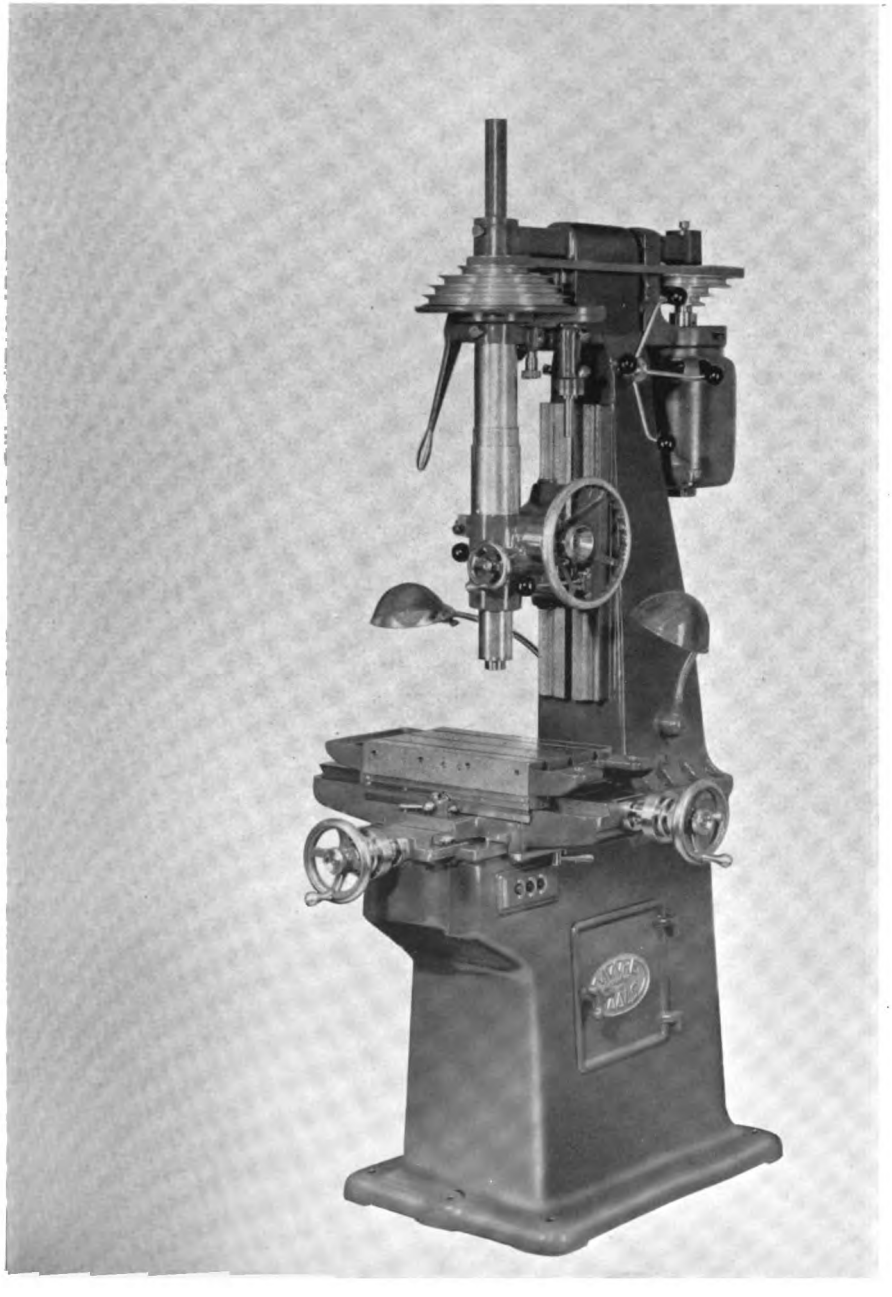
3. Through the simple expedient of pulling mating surfaces directly together. The clamping of the cross slide to the base of the Moore Jig Borer presents an example of this. Two clamp blades, one on either side, are sprung against the underside of the projecting shelves on the base, effectively locking the cross slide without influencing its position. Another example is provided by the means of locking the quill housing to the column. The quill housing is pulled straight back into a pair of prismatic Vee ways. Up-and-down travel wears the ways, of course, and the spindle center slowly approaches the column. This has no effect upon any job, however, since the wear takes place over a period of many years, and the amount worn during any particular job is so small as to be unmeasureable.

8. Magnification of Any of the Above Causes Due to Faulty Design — In general, errors of this type are minimized in design by keeping the area of action (boring) as close to all controlling ways as possible, and by avoiding the rotation of heavy masses. Fig. 91 shows how a

milling machine, for example, with a small amount of transverse looseness in its vertical ways, can create an error larger than the actual looseness, because movement is in an angular direction. The farther away from the ways, the larger the error.

In the Moore Jig Borer, Fig. 98, the designers have conscientiously considered each of the preceding points from the standpoint of pure design, from that of the builder, and from that of the user. The total value can best be appreciated from a study of its performance in subsequent chapters.

Fig. 98 — Moore Jig Borer.



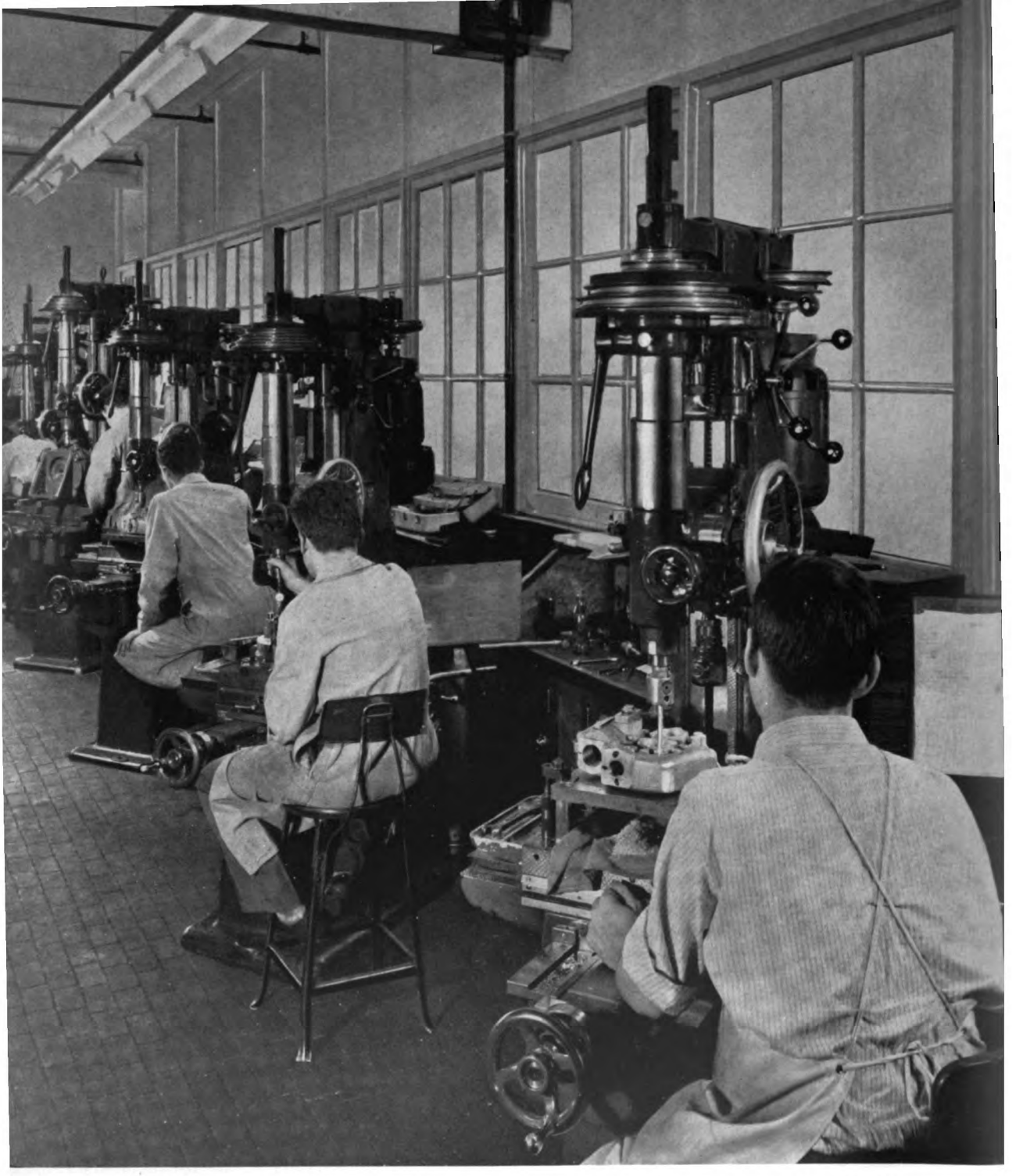


Fig. 99 — Ready access to a complete array of accessories is necessary for maximum Jig Borer efficiency — work-holding devices, cutting tools, inspection tools.

Chapter V

JIG BORING PRACTICES

ALTHOUGH the Jig Borer is probably the largest single contribution to the hole location problem, it would be a mistake to consider it *by itself* the be-all and end-all. It is insufficient unless accompanied by a full complement of accessories and operator "know-how".

Machine tool builders, although far-sighted in embodying internal improvements, often overlook features pertinent to the operation of the machine. They regard the machine as an end in itself, rather than merely a *part* of the solution to the customer's problem. Is this sufficient?

Moore engineers are not satisfied to provide the customer with just a Jig Borer. Instead, they concern themselves with giving him a *complete Jig-Boring service.* This service embraces:

1. The machine.

2. The means for making it convenient to operate.

3. The instruction necessary to its efficient operation.

4. A full complement of small tools required for the three basic steps in the hole locating process — locating, cutting and inspecting.

A complete unit of Jig-Boring service is shown in Fig. 99. Tools are near at hand for any job that may come along. The operator can reach all the machine's controls from a normal sitting position. The cabinet has built-in sections to hold all tools — a place for everything and everything in its place. The drawing board attached to the cabinet holds the drawing. A quick glance at the drawing, a shift of his eye to the dial, and the table is set to the correct figure.

Accessories and Small Tools — The accessories on succeeding pages illustrate the thoroughness in working out operational details for the Moore Jig Borer. Tools are available for all purposes, from picking up initial location, to drilling, boring and reaming, to final inspection. The purpose of all these may not be apparent until their uses are described; a listing at this point will serve to acquaint the reader with them and prepare him for the operational practices discussed in this chapter.

Fig. 100 — Desk-type cabinet for servicing Jig Borer.

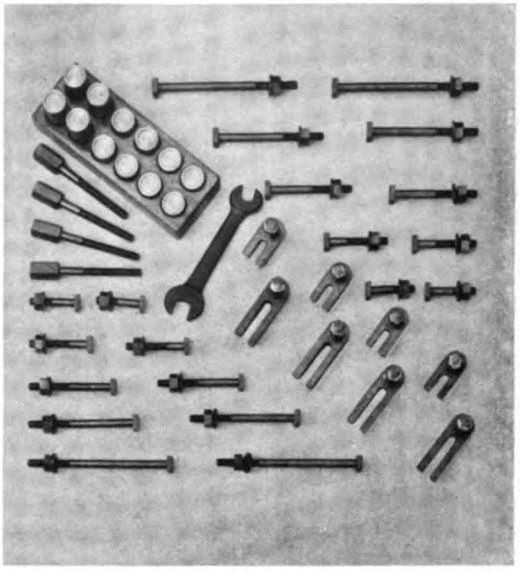


Fig. 102 — Bolts, straps, heel rests.

Storage Cabinets — Since a major consideration in overall Jig Borer efficiency is convenience, a handy storage place for tools is an important feature.

The large desk-type cabinet, Fig. 100, is recommended. This provides a place for each necessary accessory, including bolts and straps, rotary table, angle plate, small cutting tools, workpieces, or any other parts which may accumulate. A single lock and key closes all drawers and doors. An adjustable rack is provided for holding blueprints or sketches.

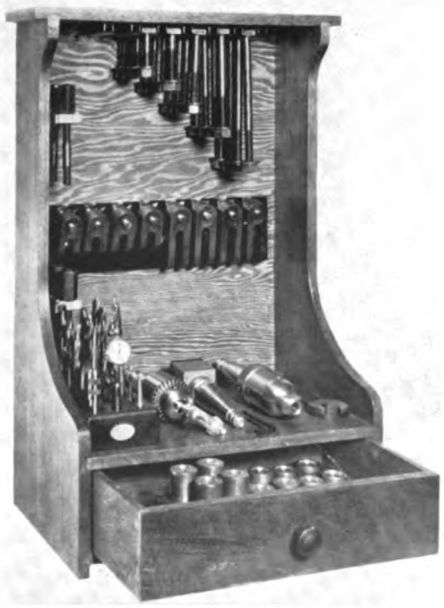


Fig. 101 — Small, bench-type cabinet.

The small cabinet, Fig. 101, makes a suitable place to store bolts and straps, pickup devices and other small tools. It is intended to stand on a bench near the Jig Borer.

Work-holding Devices — A varied assortment of work-holding devices is also advantageous. Most of the work is held by ordinary bolts and straps and it is here that maximum convenience and efficiency are desirable. Those supplied with the Moore Jig Borer are of the open-end type, Fig. 102, eliminating the necessity for re-

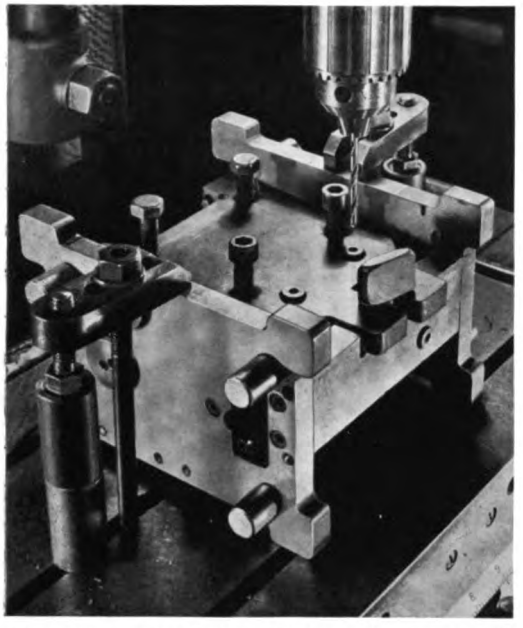


Fig. 103 — Adaptability of bolts and straps to wide variety of work.

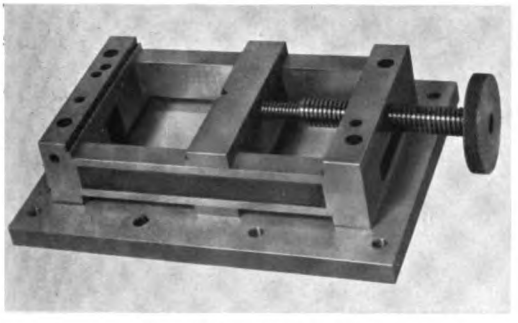


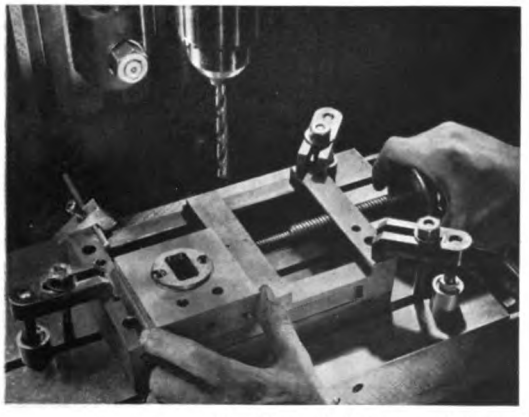
Fig. 104 — Precision vise.

moving the nut and washer from the bolt. Adjustable heel rests save the time of looking for packing of exactly the right height. Indented brass heel rests protect the table from scratching and burrs. Extension bolts and stacking of the heel rests permit clamping work of exceptional height, Fig. 103. The storage cabinets, Figs. 100 and 101, provide built-in hangers for the bolts and straps.

Other types of straps for holding small pieces or other special purposes are sometimes made by operators, Fig. 107.

The precision vise, Fig. 104, is also a valuable work-holding accessory. Equipped with step jaws to serve as parallels, a "V" slot for round work, and provision for end-stops, Fig. 105, it is ideal for small-lot production in place of drill jigs. The base plate is ground square and parallel to the stationary jaw, facilitating alignment when setting up. Jaws are 5½" wide, open to 6".

Parallel setup blocks are also available in complete sets, Fig. 106, with hold-down



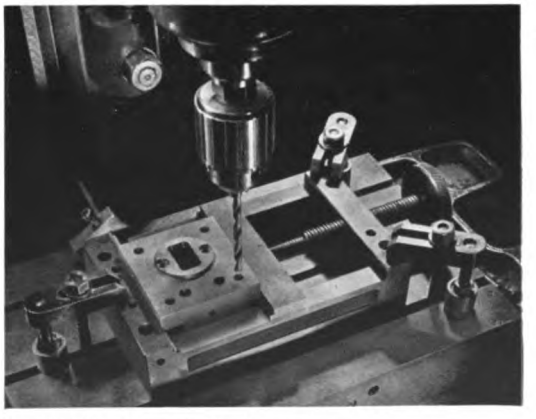


Fig. 105 — End-stops, easily attached, adapt the vise to production work.

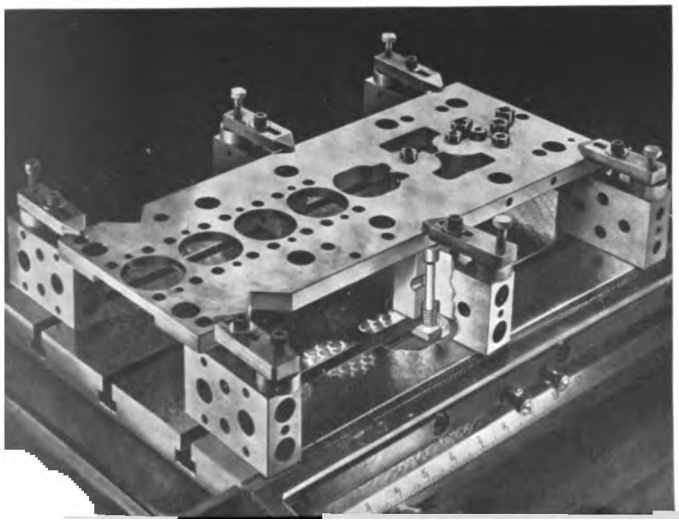
Fig. 106 — Parallel setup blocks with bolts.

bolts. The set shown consists of six each of two sizes, namely 1″ x 2″ x 3″, and ⅞″ x 1¼″ x 1½″.

They are useful in many ways:

1. Setting up jobs on Jig Borer or Jig Grinder. They can be employed to hold parts too small to hold by means of the regular bolts and straps. Their height enables the operator to measure the *bottom* of a hole, inaccessible with ordinary low parallels. Instead of using a single pair of ordinary parallels under a long, flat plate, it is often more accurate to use six setup blocks. This provides good support for the center without interference with drills and

Fig. 107 — Blocks provide good support for center of long workpiece without interference with drills.



boring tools, Fig. 107. They are also useful as end-stops or for repeating location, as in the case of production work.

2. Layout and Inspection. Since these blocks are perpendicular and held to accurate dimensions, they can be used as semi-precision measuring devices or angle blocks. Close dimensional tolerances insure interchangeability when more than one set is employed.

Furnished with each machine is a straightedge, or parallel setting bar, attached either to the front or the back edge

Fig. 108 — Parallel bar and setup blocks position work parallel to travel.

of the table. This is useful in setting up work parallel to table travel, Fig. 108.

Single-Point Boring Tools — Since single-point boring is the most accurate method of generating true hole location in soft pieces, Fig. 4, a large assortment of tools for this purpose is necessary. The operator should not be stinted in this matter. However many boring tools may be at his disposal, he finds uses for them all,

and, occasionally, gets "stuck", at that.

Adjustable boring heads top the list in importance. Two types are shown, Figs. 109, and 110, with tool bits, Fig. 111, to fit either type. Fig. 109 is a swivel-block type, while that in Fig. 110 is a dovetail-offset type. Many variations and sizes of both these general types have been made for large and small Jig Borers; both have advantages and disadvantages.

For example, the swivel-block type, Fig. 109, provides a far greater range of adjustment in proportion to its diameter than the other. This is a distinct advantage in avoiding projections on the work, such as in the boring of holes inside deep box jigs. Moreover, it presents a tapered section to the operator, permitting him better to observe the cutting action of small, short tools, which would be partially obscured by the flat bottom of the offset tool in Fig. 110.

The dovetail-offset tool, has the advantage that its overall length is somewhat shorter, promoting better rigidity. This is overcome, in the swivel-block type, by the fact that it has no gibs; it is locked between large surfaces by clamping the sides of the tool together directly upon the swivel block.

An objection frequently raised regarding the swivel type of head is that, since the tool swings on an arc, the graduations are not accurately related to tool travel. This is seldom depended upon over long

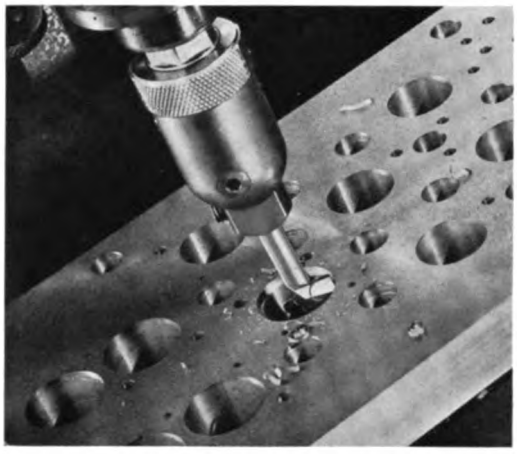


Fig. 109 — Boring head of swivel-block type.

Fig. 110 — Boring head of dovetail-offset type.

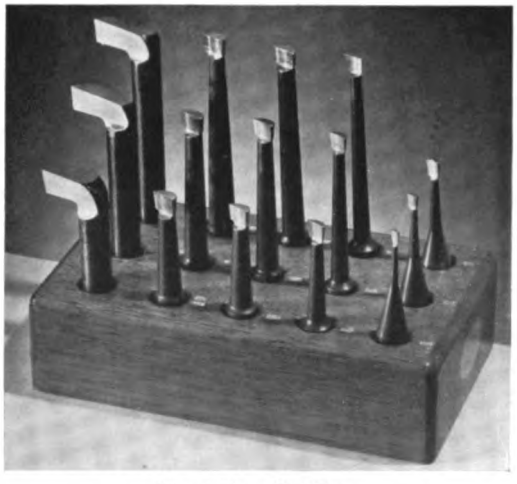


Fig. 111 — Tool bits.

ranges of travel anyway, and is accurate enough over short ranges, provided tools are of the proper length to produce a known ratio with respect to the actuating screw. In the Moore swivel-block head, three lengths of tool bit are available. The short length is such that one graduation on the dial advances the tool .001″. The others advance it .00125″ and .0015″ respectively.

The swivel-block tool has the advantage of being more easily protected from entrance of dirt, and is decidedly safer for the operator because of its shape. There are no protruding corners to bark the operator's knuckles or to damage projections on the work.

The dovetail-offset tool, Fig. 110, is at a distinct advantage in facing or squaring shoulders or in the bottoms of bushing holes, since a bit once ground parallel remains parallel over its entire travel.

It is strongly recommended that at least *two* of each type of boring tool be available to the Jig Borer operator. The advantage of this is not readily seen until pointed out. No boring tool can be moved positively over long distances of travel. Attaining the desired size is partly a matter of cut and try. When nearly to size, a trial cut is taken and carefully measured. The tool is then advanced the correct amount before taking a trial finish cut. Before going through with this finish cut, however, its size also must be carefully checked, as a safety measure. Much time can be saved by setting the tool once and then, when going to some other size, by removing the entire boring head and replacing it with another. When the original tool is replaced, it will cut to the original size without further experimentation.

The ideal adjustable boring head, in the opinion of the writer, has not yet been developed. The problem presents a real challenge to some future designer, see also page 141. Some of the desired features are these:

1. Accurate size setting.

2. Adjustability while running, to bore tapers or to face parallel surfaces, such as the tops of bosses or shoulders in holes.

3. Wide range of adjustment.

4. Rigidity to prevent chatter or poor finishes.

5. Small size for accessibility.

Various heads incorporating one or more of these features have been made but only at the sacrifice of the other points.

Due to the difficulty of quickly attaining accurate size with an adjustable boring head, another series of boring tools has been developed, Fig. 112. Five of those shown are called solid boring bars and the tool in the left foreground, for lack of a better name, is called a square tool bit collet and bit. All these tools are intended for repetitive work. They are all adjustable over a small range and may be set and left to cut to some particular size.

Fig. 112 — Assortment of boring bars and square tool bit collet.

The solid boring bars are equipped with graduated adjusting screws. The locking screws fix the tool bits firmly against two faces of a square slot. These tools repeat pre-set sizes accurately and are available in a wide variety of sizes to provide the greatest possible rigidity for each particular job. They are especially advantageous in deep holes.

The square tool bit collet, intended for smaller holes than the solid boring bars, holds a square-shanked tool bit in a cluster of eight set screws. Although the screws are not graduated, adjustment in small increments is conveniently made. Once set, duplication of size is assured. For applications of these tools, see also page 144.

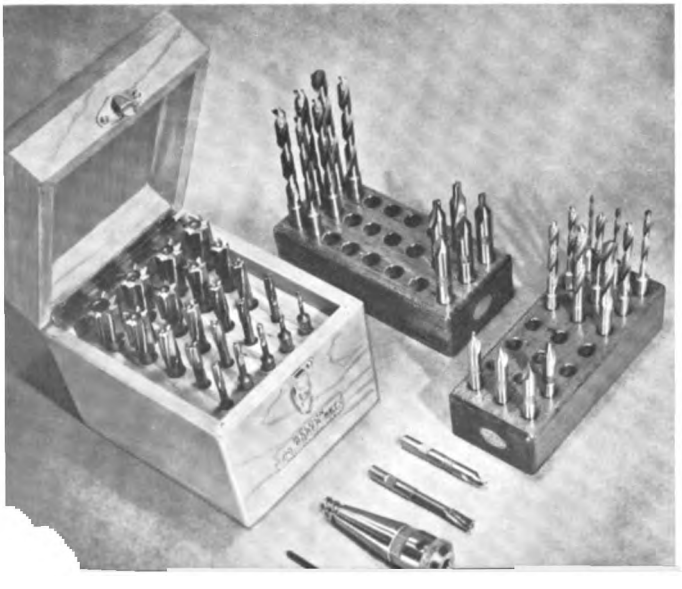
Carbide Tools — Carbide-tipped tool bits may be employed in any of the foregoing boring heads or boring bars. They are, in fact, of considerable advantage on some types of work, especially on cast iron or non-ferrous materials, and on production jobs. Modern developments in carbide also make them useful in cutting steel, especially the wear-resistant high-speed and high-carbon, high-chromium steels used for high-production press tools.

In view of the extreme hardness and wear-resistance of carbide tools, their introduction into Jig Borers has been somewhat slower than might be anticipated. This is partly due to the type of work done, and partly to the difficulty in designing tools rigid enough to function properly, yet small enough to enter the hole being bored.

For best efficiency, the carbide tool must be specially tailored to suit each particular cut and must be sharpened on diamond wheels. The cost of this is more readily absorbed on production work than on the one-at-a-time tool job. Carbides are, therefore, better adapted to production than to the wide variety of jobs to which the tool room is accustomed. Since most Jig Borers are located in tool rooms, where carbide tools are not customarily used to a very large extent on other operations, Jig Borer operators have neither the habit, equipment, nor the opportunity to develop them. Production shops, on the other hand, where the carbide practice is already established, use carbide tools to a considerable extent in the Jig Borer.

Although extremely hard and wear-resistant, carbides are subject to the disadvantage that they are brittle, and must be rigidly supported to prevent them from chattering and chipping their cutting edges. On heavy turning machines, such as turret lathes, heavy rigid holders are provided for both the work and the tool, and high cutting efficiency is achieved. The nature of the work performed in the Jig Borer, that of boring holes, precludes this to some extent. The tool bit must be small enough to go in the hole and provide chip clearance, and cannot be rigid enough for best efficiency. Chip removal is also a problem. On external work, in turret lathes, a chip breaker is ground into the cutting edge of the tool, to break up the chip, or, at least to curl it, and prevent it from coming out in a straight, flat ribbon. This is also advantageous in hole boring. A chip coming out of a hole winds itself around the tool, clogging the hole, and work must be periodically stopped to clear the chips away. Unfortunately, the action of the chip breaker, in breaking the chips, adds to the force required for the cut, and further increases the necessity for rigidity.

Fig. 113 — Collet, spotters, drills and end reamers.



In spite of these limitations, carbides are proving their usefulness. In materials such as brass, bronze, aluminum, and cast iron, having low tensile strengths, the chips break readily. The machine can be run at high speeds, and boring is done with great rapidity. Also, the increasing use of high-speed and high-carbon, high-chromium steels for cutting dies, presents a problem. These steels are employed because they are wear-resistant; even in their annealed state they are difficult to machine. High-speed steel tools do not hold size well, but wear rapidly. Carbide tools, being even more wear-resistant, if handled carefully, hold a sharp cutting edge when machining these steels.

Miscellaneous Cutting Tool Systems — In addition to single-point boring, other cutting methods have been developed, not only to finish holes to size, but to facilitate removal of large amounts of stock from holes prior to finishing.

Prominent among these methods is a system built around the so-called "End Reamer", Fig. 113, so named because it is intended to be fed straight down into a roughed hole, cutting only on the end. The end reamer partakes partially of the nature of a boring tool, and partially of that of a reamer. It is intended to be held rigidly and to run perfectly true, so that

the hole is located and sized at the same time. Actually, perfection in either of these respects is never achieved. It always springs a little due to cutting pressure, and, unless carefully indicated before each use, runs out a little. These conditions conspire to alter location and make the hole oversize. The method is extremely fast, however, and is worth some attention to the necessary details of getting it to operate. When originally purchased, each end reamer should be indicated in the same collet and same machine in which it is to be used. A slight amount of peening may be necessary to make it run within .0002″, checked on the teeth. In addition, the writer considers it advisable to break the square corners of the teeth slightly with a stone. If the cutting corners are left perfectly square, better location is achieved, but the eccentricity is liable to make it cut oversize. Breaking the corners naturally causes the end reamer to follow the original error in the hole, but it will also cut more closely to size.

Slightly breaking the corners creates a compromise between these conditions. With a reasonable amount of care, the operator should experience no great difficulty in obtaining accuracy *both* as to location and size within ±.0005″.

To obtain the fastest production from end reamers, the Moore Company has developed a system of spotters and reamer drills to be used with them, Fig. 113. These tools fit the same collet as the end reamer, and may be interchanged without removing the collet from the machine. The difference in action between this use of the center drill, or spotter, and that in Fig. 24, should be carefully noted. In the present case, the spotter should be rigid because hole location is to be determined from the *spindle axis.* In the previous case, hole location was determined by the prick-punch mark on the workpiece.

A controversy exists regarding the best holding method for end reamers, one school of thought contending that the taper shank holds it more accurately than the straight shank, with its side pressure from the set screw. Under ideal conditions, this is undoubtedly true. In practice, however, there are two objections:

1. A particle of dirt in the collet or on the shank deflects it from its true position, unbeknown to the operator. This is especially objectionable in small sizes, such as No. 1 and No. 2 Morse, since it is not easy to wipe such small holes clean, especially if particles are imbedded. A close-fitting straight shank, on the other hand, cannot be inserted unless it is clean. Any interference is an immediate warning of dirt or nicks.

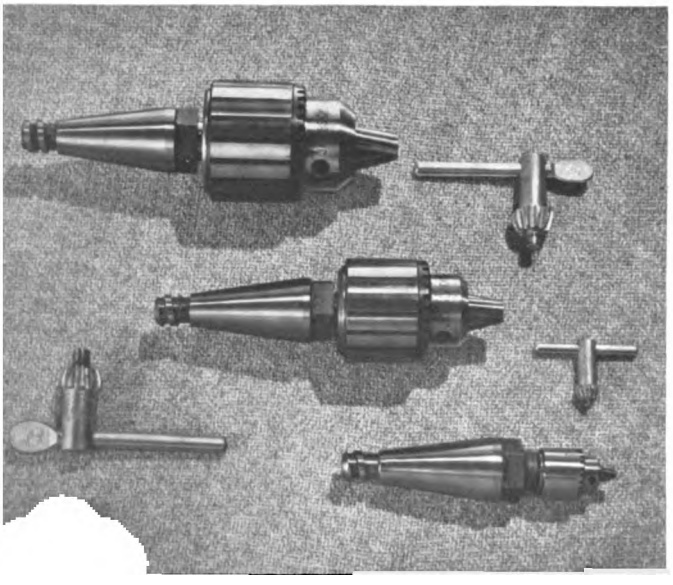
2. The tapered collet must be removed from the machine each time the end reamer is removed. This slows up operations and loses most of the value of this otherwise rapid method.

End reamers are customarily available in fractional sizes, in increments of 1/32" or 1/16". In addition to these, if the holes are subsequently to be ground, as in a Jig Grinder, a complete set of end reamers .008" to .012" undersize, along with the proper reamer drills, is advocated. Greater leeway in accuracy is then permissible; it is merely necessary to leave sufficient, but not excessive, stock to clean up by grinding.

The Jig Borer operator should also have at his disposal complete sets of standard jobbers' length letter, number, and fractional drills up to 1/2", and precision drill chucks for holding them, such as those in Fig. 114. The largest shown has a special capacity of 33/64", the smallest 1/8". Larger sizes are available for larger Jig Borers than the Moore.

There is a peculiar reason for the special 33/64" capacity. Standard drills in sizes over 1/2" are available only with taper shanks, or taper length, straight shanks. They are much too long for most Jig Borer applications, especially for tall box jigs. They must be cut off and the shanks turned down, rendering them unfit for their usual purposes in lathes, radial drills and the like. Moore, therefore, decided to establish a special short drill series, in all fractional sizes from 1/2" to 1", with shanks approximately 1/2" in diameter. It was observed that some operators might unthinkingly attempt to hold these drills in the 1/2" end reamer collet, an undesirable practice because drills in these large sizes would put undue wear and abuse on this finely made tool. Accordingly, these large drills are made with shanks slightly *over* 1/2", rendering their use in this collet impossible. For the same reason shanks on sweep tools, Fig. 118, are also made oversize. The 1/2" drill chuck, in turn, must have sufficient capacity to hold these drills and tools. 33/64" was, therefore, established as the special capacity for this chuck.

Fig. 114 — Standard drill chucks with shanks to fit Moore Jig Borer.



All three sizes of drill chuck are recommended. In case the largest chuck becomes inaccurate because of extensive service, the 3/8" and 1/8" chucks are available for fine, accurate spotting or drilling.

The usual practice to start a hole is to employ a center drill, or spotter. Spotters with special shanks, above described, are available in case the hole is to be end reamed. In most other cases, standard center drills, held in the drill chuck, are employed. Very small holes, from about 1/16" down, present a special problem. It is difficult to single-point bore these holes;

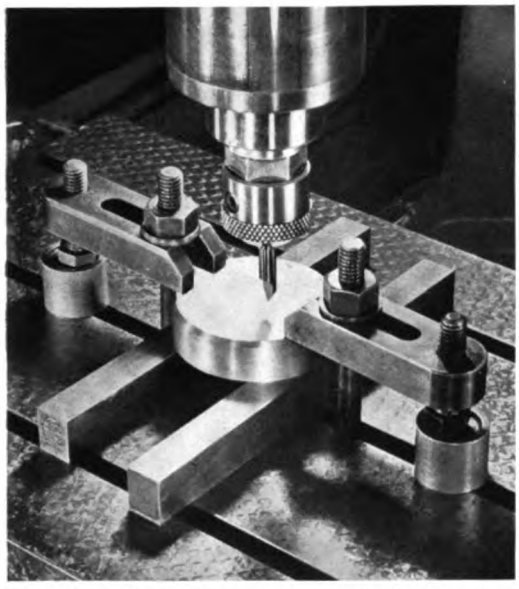


Fig. 115 — Spotter for very small holes, must be kept sharp for best results.

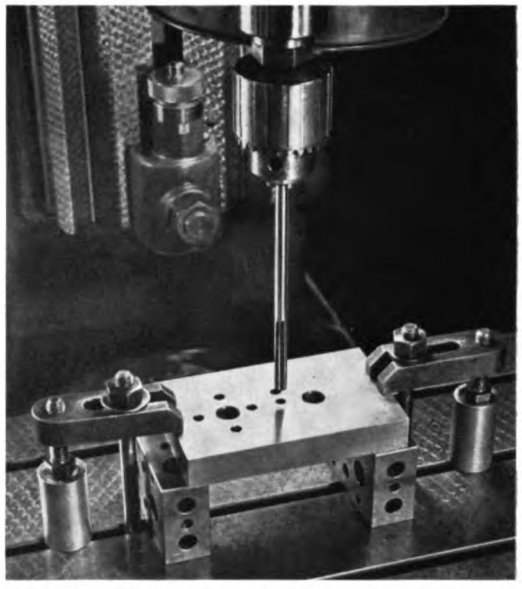


Fig. 116 — Rose or fluted reamer — reaming a hole previously bored.

at any rate, small drills follow a spot very accurately, provided the spotter is true and sharp. For this reason, special spotters for very small holes, Fig. 115, are available. These are intended to be held in the $\frac{3}{8}$″ end reamer collet to make them run true, although followed by small drills held in the drill chuck. These spotters must be kept sharp, to prevent the formation of a cold-worked flat in the bottom of the spot. Used carefully, small drills follow them accurately enough for many purposes.

Some operators like to have a set of ordinary rose reamers, or fluted reamers, for sizing holes. They save the cutting and trying required to set a boring tool to single-point bore the hole to size. The principle upon which these operate is entirely different from that of the end reamer. The shank is long, and somewhat slender, to permit it to float, and align itself with a hole already bored nearly to size, Fig. 116. Inaccuracies of the shank or chuck sometimes cause it to run out. If not excessive, this is not objectionable, since its center of rotation is held by the axis of the spindle and the bored hole.

The rose reamer, if carefully handled, and, if not too much stock is left for reaming (.001″ to .003″), will consistently produce somewhat more accurate results than the end reamer and save considerable time in setting boring tools.

The drills, end mills, and sweeping tools in Figs. 117 and 118 are, in general, suitable for squaring up shoulders in the bottoms of holes, or sweeping bosses. The twist drills, Fig. 117, are standard twist drills ground straight across. This drill exerts considerable pressure on the sides of

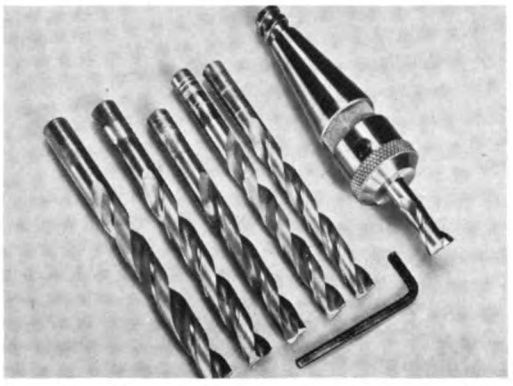


Fig. 117 — Twist drills for squaring bottoms of holes.

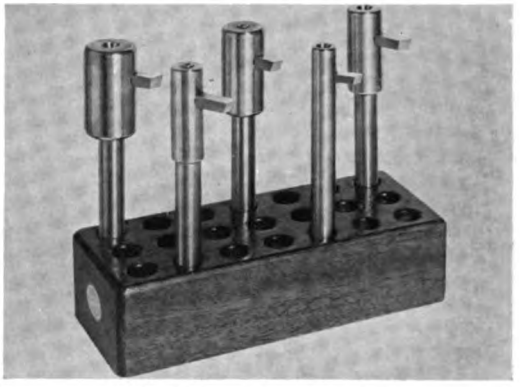


Fig. 118 — Sweeping tools.

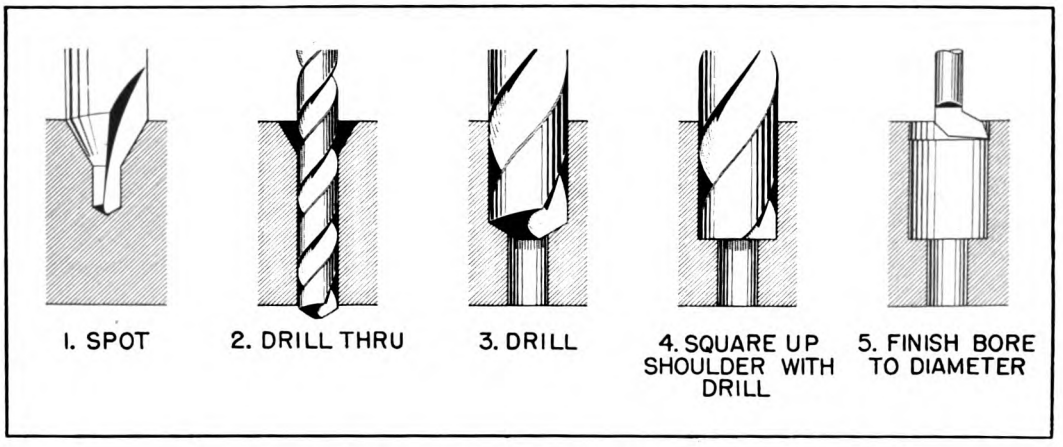


Fig. 119 — Sequence of operations in drilling and boring hole with shoulder.

the hole. To prevent damage to the hole, the shoulder squaring should be done before the finish boring. The drills or end mills used for this purpose, therefore, should be approximately $\frac{1}{64}$″ under fractional sizes. Fig. 119 illustrates the sequence of operations. If a rose reamer, Fig. 116, instead of a single-point tool, is employed for finishing the shoulder hole to size, the radius on the cutting corner of the reamer must be small, to permit sizing close to the bottom of the hole.

Pilots of sweeping tools are made to fractional sizes. Being smooth and hard, they do not damage previously-finished holes. Fig. 120 illustrates an important purpose of the sweeping tool, namely, rapid removal of large amounts of stock. The sideways thrust of a tool taking a large cut is heavy. A single-point boring tool transmits this thrust directly to the spindle, whereas the sweeping tool transmits it to the workpiece, saves straining the spindle and prevents chatter. Fig. 121

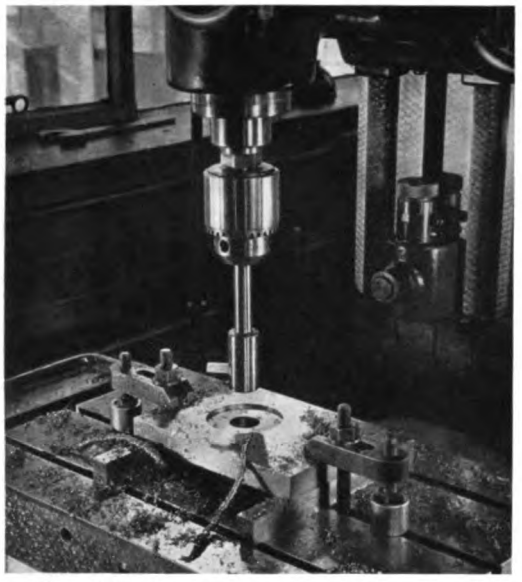


Fig. 120 — Rapid stock removal with sweep tool.

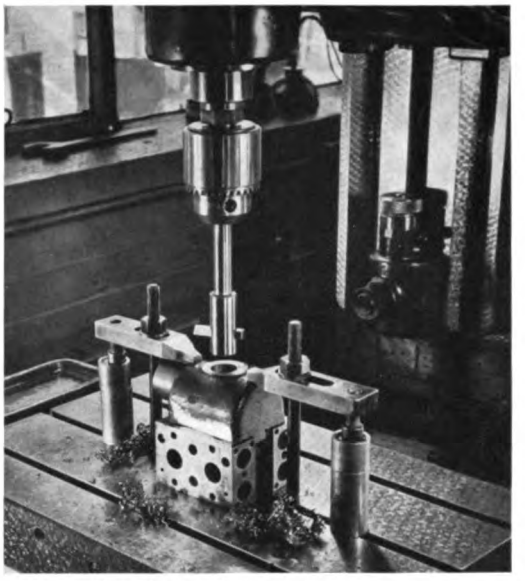


Fig. 121 — Squaring face of boss.

illustrates use of the sweeping tool in squaring up the face of a boss.

Cutting Lubricants — The use of coolants, or cutting lubricants, is advisable when boring many types of material, for the same reasons as when performing any other machining operation, such as milling, turning or drilling. A film of oil lubricates the chips as it slides over the edge of the tool bit. This reduces power consumption, cools the work, and produces a better finish.

Jig Borers are not customarily equipped with built-in coolant pumps or coolant spouts; for most purposes this is considered unnecessary. Oil may be squirted into the hole from a hand oil can, or enough is usually supplied by holding a small, oil-soaked paint brush against the tool bit as it turns.

For cutting cold-drawn, or most water or oil-hardened steels, lard oil or any of the commercial cutting oils will be found satisfactory. In a pinch even light machine oil will do. Brass and bronze usually require no coolant at all.

It is usually impossible to machine aluminum or aluminum alloys to a good finish without a coolant. Different alloys appear to require different coolants. The following have been used, some with better results than others, on some alloys: water, kerosene, alcohol, turpentine.

Cast iron and high-carbon, high-chromium steels usually cut better when dry. Cast iron exerts an abrasive action on the tool, wearing a little flat at the point of contact. Any lubricant tends to build a film on the surface of the work, preventing the tool from penetrating. For this reason,

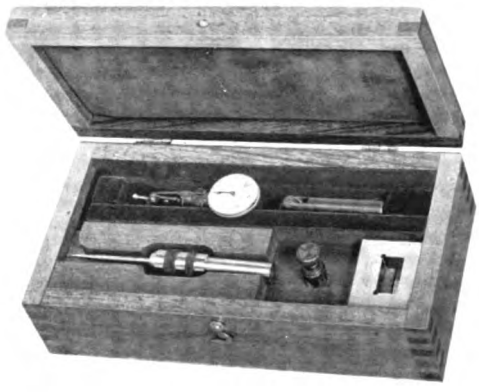


Fig. 122 — Indicator set.

coolants tend to cause the cutting tool to produce a smaller-diameter hole than it would if run dry. High-carbon, high-chromium steels are difficult to penetrate under any conditions. Lubrication serves to increase this difficulty.

Locating, Inspection, Measuring Tools — A typical kit, Fig. 122, for performing most locational checking operations consists of an indicator with holder, an edge finder and a wiggler, or line finder. The preferred type of indicator is that with the extension lever-type tip, such as the "Last Word," "Federal," or "Ideal," since they are so designed as to approach the hole and transmit the motion in the right directions without any additional attachments.

Most attempts to adapt plunger-type indicators to this purpose are disappointing, due to the necessity for additional levers or linkages, to change the direction of motion. Likewise, the various rotating devices, to transmit the motion to the indicator while holding the indicator stationary, necessitate levers and sliding parts. In addition to being clumsy and promoting great overhang, these introduce further friction, reducing the sensitiveness of the indicator system.

For these reasons, the writer prefers the

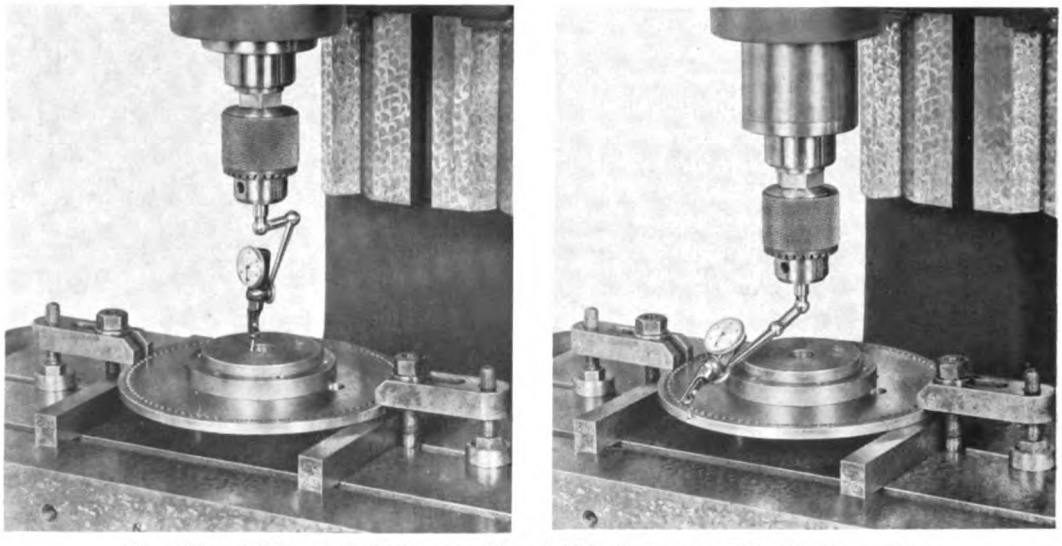


Fig. 123 — Wide range of indicator holder. Held firmly in any position by friction joint.

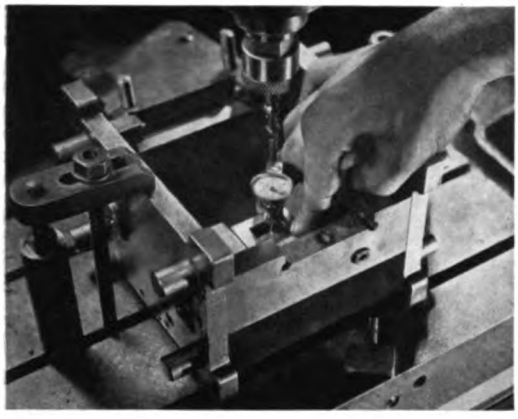


Fig. 124 — Indicator holder straightened out, to reach obscure pickup.

extension-lever type, although it sometimes necessitates reading from the back of the machine, or with a mirror, Figs 126 and 127. After a little experience, pickups are made rapidly.

The indicator holder is an important part of the system. This must not be so bulky as to interfere with projections on the work. It must have a wide range of travel, to encompass small and large parts; yet it must be sufficiently rigid to overcome the internal friction of the indicator and give true readings. Refer also to pages 244 and 245. The holder in Figs. 123 and 124 provides an excellent example. The friction-jointed design permits a wide range of usefulness: small diameters, large diameters, or deep down in an obscure spot in a box jig.

The edge finder is used to centralize the spindle with the edge of a workpiece, Figs. 125 to 127. It is so made that its locating surface is ground and lapped centrally with the indicating lips. There are definite advantages from this particular design:

1. Since it is to be used for reference in only one direction at a time, the edge finder should not be a round piece or a round hole. If so, it would be necessary to indicate it in *both* directions, to render the readings in the desired direction significant. This would necessitate clamping it firmly in place, to prevent its slipping. This is unnecessary with the Moore design. It may be held in place with the fingers. Endwise slipping will have no effect upon it.

2. With the Moore design, not only are the lips central, but each is also a known distance (.200″) from the lapped locating surface. After picking up the edge, Figs. 125 and 126, the workpiece may be advanced or backed away .200″, and the edge itself indicated, Fig. 127, to assure the operator that the edge finder has made good contact and that the edge is clean, free from burrs, and perpendicular.

Fig. 128 shows a method of picking up an edge *without* an edge finder. This is somewhat less convenient, due to the necessity for lowering or raising the spindle when making readings.

The wiggler, or line finder, is employed when the only usable pickup point is a line scribed on the work or roughly to pick up an edge, Fig. 160. Held in the machine spindle and rotated, it can be made to run true by a touch of the finger, or running it in the notched line of a

Figs. 125, 126 — Indicating lips of edge finder. Mirror aids reading when indicator is reversed.

Fig. 127 — Indicator directly against workpiece shows up surface defects or errors in setting. Also automatically checks accuracy and contact of working edge of edge finder.

scale. It is now brought down close to the line on the workpiece, and examined under a magnifying glass for setting the work to location. The microscope may also be used for this purpose, with considerably greater accuracy.

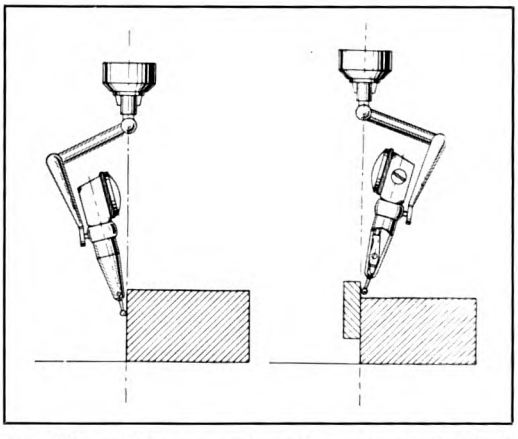


Fig. 128 — Picking up edge without edge finder. Indicator lowered, touching edge of workpiece. Raised, touching gage block against edge. Center line through spindle and edge of work.

Although most of the pickup, or location, operations are performed better and more easily with the indicator set, a locating microscope, Fig. 129, is also a valuable adjunct for these reasons:

1. Greater accuracy when picking up scribed lines or points than possible with the wiggler, or line finder.

2. Locating workpieces with holes, edges, slots, or other reference points too small for the indicator and edge finder.

3. Converting the Jig Borer to an inspection machine, like a toolmaker's microscope, for hole position, contours, slots, surface conditions or other small, irregular jobs. See pages 235 to 246 for full discussion of Jig Borer as inspection machine.

To attain the fullest use, the microscope should have certain definite characteristics:

1. It should revert the image to upright. Most microscopes produce inverted images, so that the operator must mentally transpose dimensions and contours. This is confusing and causes errors. The Moore Microscope contains a roof prism to revert the image to its natural position.

2. The field of vision should be large enough to encompass a large portion of the workpiece.

3. Magnification should be great enough to see a "tenth".

4. The reticle should be well covered with reference points. In the Moore Microscope these points assume the form of a large number of concentric circles, and two pairs of crossed center lines. This permits locating of holes, radii, or other surfaces in a wide variety of sizes.

Fig. 129 — In addition to serving as pickup device, microscope transforms Jig Borer into inspection machine.

5. It must be adjustable, in order that the optical center may be aligned with the main spindle. This optical center should be checked and adjusted *each* time it is attached to the machine.

In addition to locating instruments, it is essential to have a variety of devices for measuring hole size.

Most used among these is the commonly-known inside caliper. This is set just to

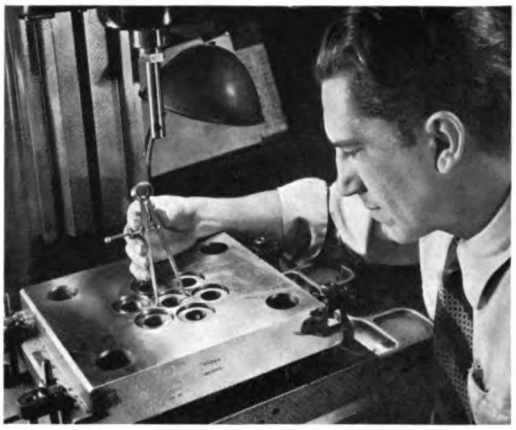


Fig. 130 — Checking hole with inside caliper.

Fig. 131 — Transferring measurement to micrometer.

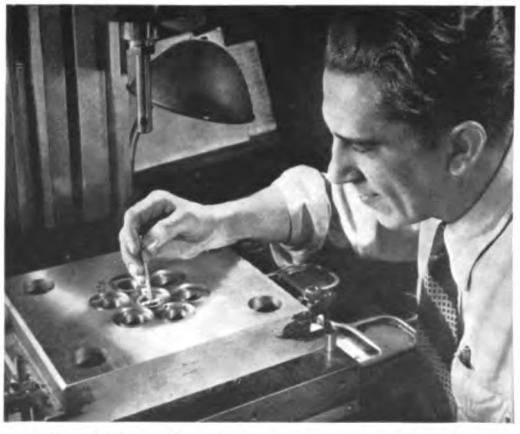


Fig. 132 — The telescopic gage is more rigid.

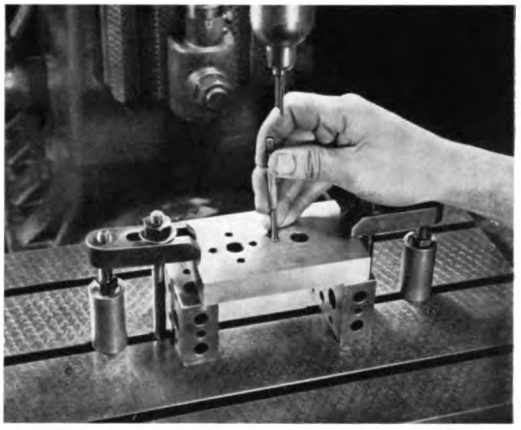


Fig. 133 — Variation of telescopic gage for small holes.

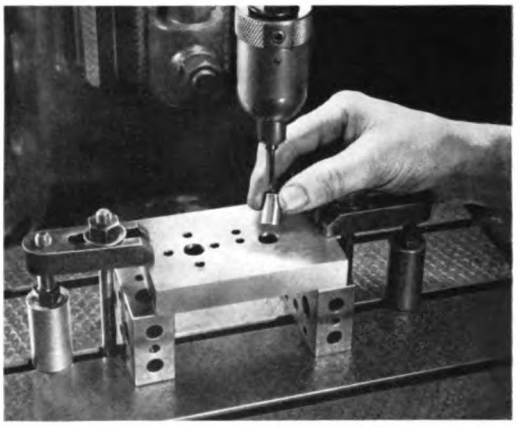


Fig. 134 — Plug gage, most satisfactory for final sizing.

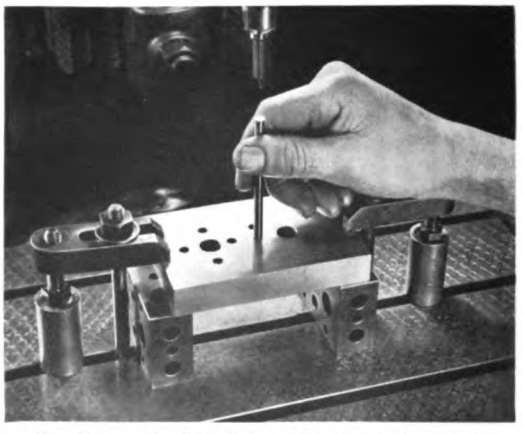


Fig. 135 — Checking hole with tapered plug gage.

touch the sides of the hole, the measurement then being transferred to a micrometer, Figs. 130 and 131.

Since calipers of this type lack rigidity, and, therefore, sensitiveness, another type has been developed, Fig. 132, called a telescopic gage. Being more rigid, greater accuracy can be expected from this type. Fig. 133 shows a further development for measuring smaller holes. Measurements from the telescopic gage and the small hole gage are transferred to micrometers, in the same manner as from inside calipers, Fig. 131.

More accurate than calipers or telescopic gages is the plug gage, Fig. 134. Plug gages made for Jig Boring should be short, to permit getting them under the retracted boring tool. The plug gage is the most accurate means of checking a hole diameter, but has the serious limitation of being effective only to check a hole whose size is exactly that of the gage. It is impossible to measure the hole before it is finished or to determine how much stock remains to be removed unless an infinite number of gage sizes is available.

Fig. 136 — Checking size of tapered plug at point of contact.

Fig. 137 — Set of leaf taper gages in box.

To overcome the limitation in increments of the plug gage, another device is sometimes employed, that of *tapered* plug gages, Fig. 135. The tapered plug gage is inserted into the hole, the measurement being transferred to micrometers or to a comparator, Fig. 136. The tapered plug gage also has a disadvantage. In order to give it a substantial range of sizes, it must be made with a taper too steep to give it good accuracy, or it must be excessively long to go through the work or under the cutting tool. Excessive length is particularly objectionable in the case of bottomed holes, since the gage might hit the bottom of the hole before it contacts the sides.

Another hole-size measuring device, developed to its present state by the Moore Company, is the flat leaf taper gage, Fig.

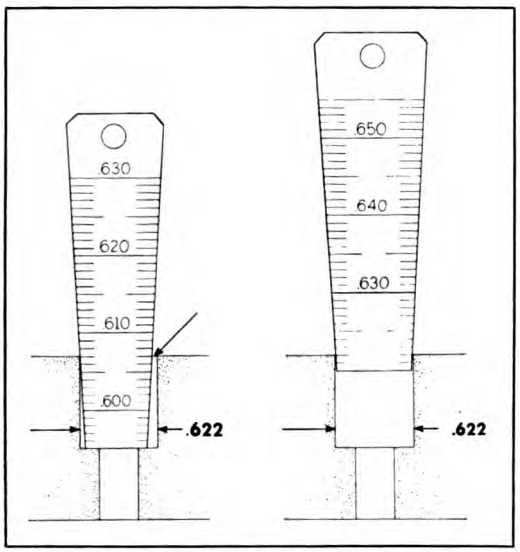


Fig. 138 — Size of hole is read directly from gage at point of contact with edges of hole. To prevent interference from shoulder, set is divided into large number of leaves with overlapping graduations.

137. This contacts the end of the hole at two points, Fig. 138, the depth to which it enters determining hole size, which is read directly from the gage. Each leaf is graduated in thousandths and numbered to indicate size. The set is divided into a sufficient number of leaves, graduations at the end of each overlapping with those of the next, Fig. 139, to permit measuring bottomed holes, Fig. 138. Overall length is short enough to clear cutting tools, Fig. 140.

Being tapered, they cannot measure diameters of any part of the hole but the end. They cannot determine taper or bell-mouth, and they cannot determine hole size to a "tenth". For roughing or approaching finish sizes, however, they are a tremendous time-saver, and, by contrast with other gaging instruments, very low-priced.

Various other hole-measuring devices are employed. The inside micrometer, for example, is common to most toolmakers. It consists basically of a micrometer screw and thimble, with extension tips to adapt it to various hole sizes. The micrometer is screwed out until the tips contact the sides of the hole, size being read directly from the thimble.

Another is the vernier caliper, Fig. 28. A graduated scale is fitted with one fixed and one sliding trammel. The ends of the

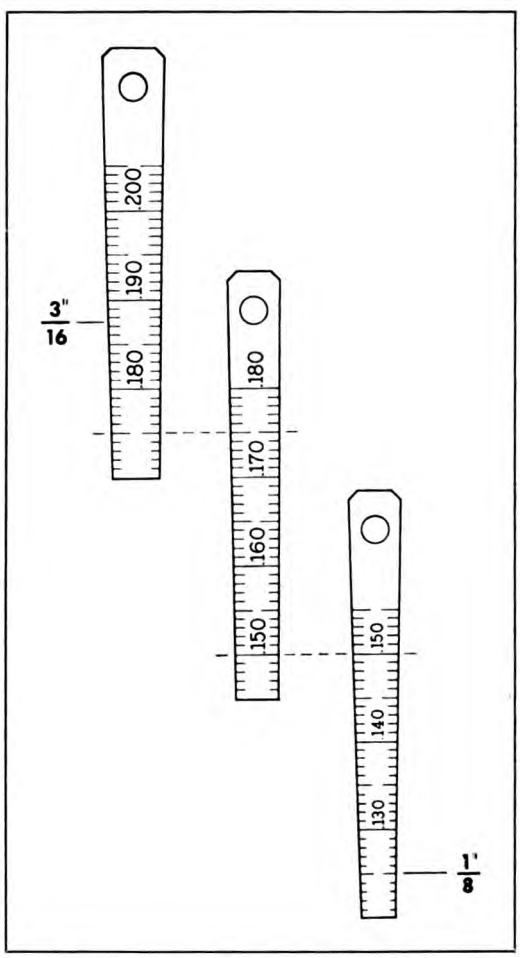


Fig. 139 — Method of overlapping graduation.

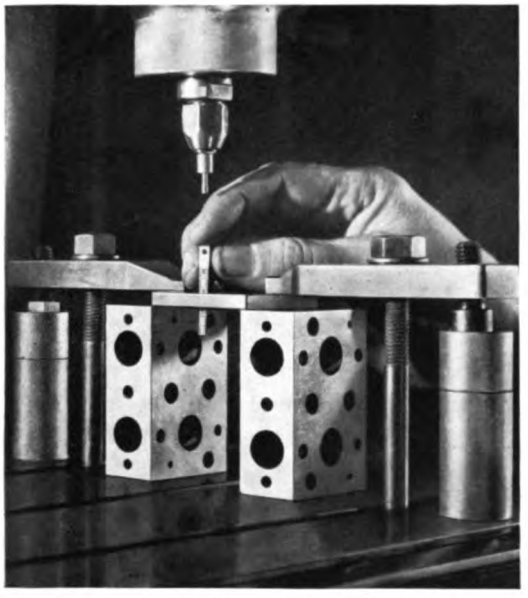


Fig. 140 — Gage is short enough to clear cutting tools.

trammels are cut down to form fingers, which contact the sides of the hole. Size may be read directly from the scale.

Recent years have witnessed the development of other new and highly accurate tools such as the internal indicator, and the air gage, more fully discussed on page 173.

Angular Spacing Devices — To facilitate spacing of holes on angles, three basic pieces of equipment are available for the Moore Jig Borer: The Rotary Table, the Right Angle Plate and the Micro-Sine Table.

Rotary Table — The 10″ rotary table, Fig. 141, is especially designed for spacing holes accurately in a circle. It is sturdily built, the base of semi-steel and the top of solid forged steel, both carefully seasoned and scraped. A hardened, ground and lapped bushing in the center of the table can be used to locate workpieces centrally on the table. The hole in this bushing is concentric with the axis of the table within .0001″.

This table is accurately graduated in one-half degrees and, by means of a vernier, reads direct in increments of one minute. The lines are extremely fine and, therefore, close settings are possible. Holes can be spaced on this table within ±.0002″ on an 8″ diameter.

In order to facilitate starting with a zero reading, the vernier plate can be adjusted 1½ degrees each side of the center. The worm can be disengaged from the worm wheel by a knurled sleeve, allowing the table to spin freely for indicating purposes. The rotary table is also a convenient device for *orienting* the work, regardless of angular divisions, see pages 178 and 179.

A special adaptation of the rotary table, Fig. 142, permits more rapid settings than

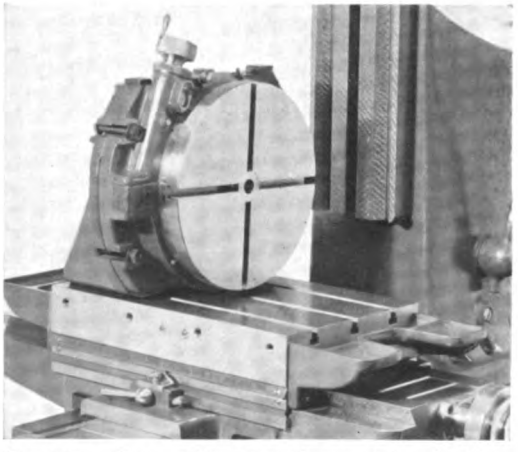


Fig. 141 — Rotary table, normally mounted on Jig Borer table, may also be attached to right-angle plate for radial or tangential holes.

Fig. 142 — Rotary table arranged with rapid indexing plate for repetitive work.

is possible with the conventional rotary table. An indexing plate is fitted and doweled to a concentric rabbet turned on the rotary table top. A plunger, operating from the base, and inserted into the indexing holes, establishes angular location. Plates are interchangeable, standardized as to sizes and dowel locations.

This makes a handy device for cases where a number of holes on a circle must be repeated. This applies, for example, to some kinds of tool work, such as lamination dies, where the circle of holes must be repeated in the die, stripper, and punch plate. Figs. 292 to 296 show the adaptability of this general type of fixture to production work, also.

The right angle plate, Fig. 141, is provided for radial or tangential spacing, holding the rotary table in a vertical position.

Micro-Sine Table — This table is used for holding the rotary table at any desired angle. It can also be used to hold jobs where angular holes are to be bored, Fig. 143. The angle is determined and set according to the sine bar principle, using gage blocks. The table will swivel from zero to 90°.

The advantage of having the rotary table and sine table in two units is that either can be used separately, thereby getting the maximum of useful machine height.

Depth Measuring Features—The Moore Jig Borer has three distinct devices for measuring and controlling the depth of holes, Fig. 144.

1. Graduated dial and vernier on pinion shaft, reading to .001″, can be seen in the photograph—between the large handwheel and the main housing. The dial, which can be set to zero at any position of vertical

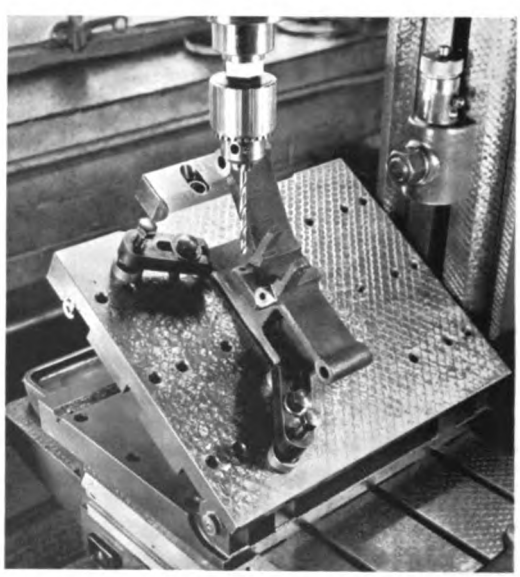


Fig. 143 — Micro-sine plate may also be employed in conjunction with rotary table for compound angles.

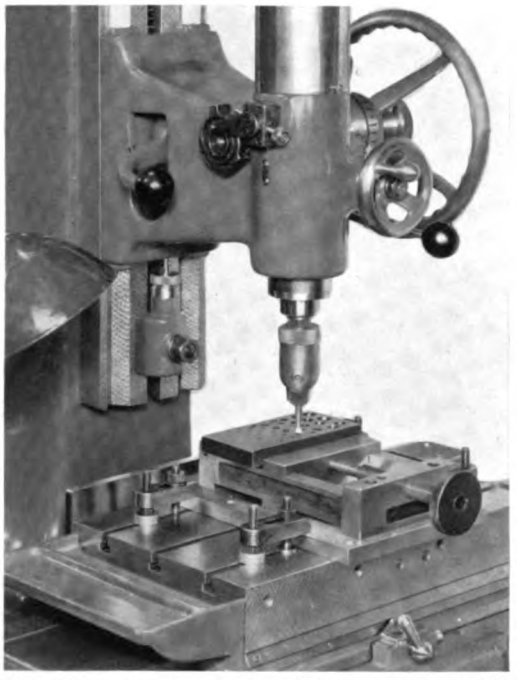


Fig. 144 — Depth-measuring features — vertical dial, adjustable positive stop, micrometer stop for quill housing.

travel, is graduated in hundredths and reads, by means of a vernier, in thousandths.

2. Adjustable positive stop, on left end of pinion shaft, with micro adjustment. This type of stop enables the operator to use the full travel without the usual interference, since a pin in the spiral groove of the stop itself swings the limiting screw clear on the up-stroke. Micro adjustment is attained by turning the limiting screw.

3. Micrometer stop on column. This husky, accurate stop, used in conjunction with the previously mentioned depth-measuring features, simplifies many otherwise difficult tasks. Between operations, it often becomes necessary to raise the spindle housing. As a result, depth settings of the positive stop and graduated hand feed dial are lost. Use of the micrometer stop, however, permits the return of the housing to its original setting. It can be adjusted for height in increments of .001″ or less.

Clamping and adjusting are accomplished by means of hardened, thread-ground screws. The setting dial is graduated in thousandths and, once set, is locked by a small knurled screw.

Riser Block, Sub-Table, and Extension Plate — In response to the demand from many users for a means of increasing capacity of the Moore Jig Borer without seriously impairing its accuracy or convenience, a riser block, sub-table, and extension plate have been developed.

The riser block is installed between the base and column of the machine, Fig. 145, to increase the working height. With the riser block in place, it is no longer possible to lower the quill and spindle far enough to reach thin, flat workpieces on low parallels. The sub-table restores the original table to spindle relationship. It is the same

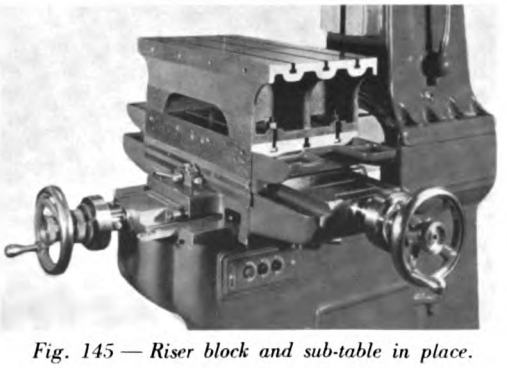


Fig. 145 — Riser block and sub-table in place.

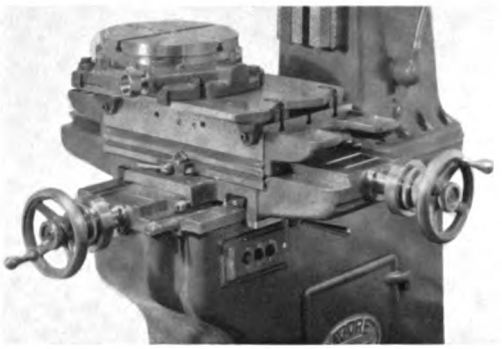


Fig. 146 — Extension plate facilitates boring of holes on large diameter circle.

width as the table, but 20 inches long, permitting the clamping of longer pieces than directly on the table.

The extension plate offsets the rotary table forward from the center of the Jig Borer table, Fig. 146, its purpose being to increase the size of the circle of holes which may be bored with the rotary table. With this device, it is possible with the Moore Jig Borer to bore holes on a diameter up to approximately 22″. It is set parallel to table travel by means of scraped aligning lugs. This permits boring both axial holes and radial holes in the same workpiece without disturbing its setting on the rotary table.

The Coordinate Location System —The Coordinate Location System is the result of the long search for a method of establishing location by means extraneous to the workpiece. Buttons, layouts and otherwise tedious and laborious procedures are largely eliminated. It attains its best efficiency in the Moore Jig Borer because of the rapidity of making table settings, and because of the overall compactness and convenience of the machine.

This permits the best sequence of operations on the workpiece, that of spotting, drilling, and rough boring all holes on the workpiece before finish-boring any of them, thus insuring the best uniformity of conditions for the finish-boring, see also pages 70 and 71.

To follow this sequence to best advantage, work should be laid out in coordinates. If drawings are not supplied in this form, the operator should be sufficiently acquainted with the practice that he can calculate them himself.

There are two general types of coordinate dimension:

1. Rectangular coordinates, for rectilinear movement.

2. Polar coordinates, for holes on circles, showing angles and distances from a zero line and center. Used with the rotary table.

Rectangular Coordinates — In the Coordinate Location System with the Moore Jig Borer, the workpiece is bracketed within a pair of imaginary crossed zero lines, horizontal and vertical, intersecting at the upper left-hand corner of the table, and in the same relative positions on the drawing. Coordinates are dimensions from these zero lines. They are not customarily written on dimension lines terminated by arrows, but on or above the lines whose distance from zero they are intended to

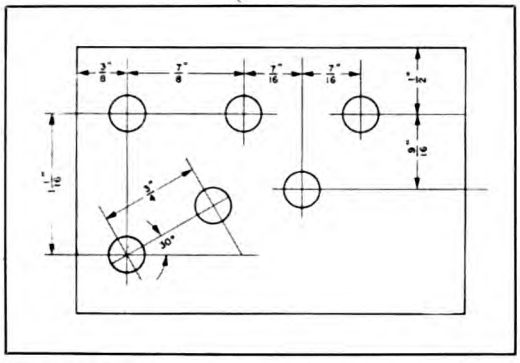


Fig. 147 — Conventionally dimensioned drawing.

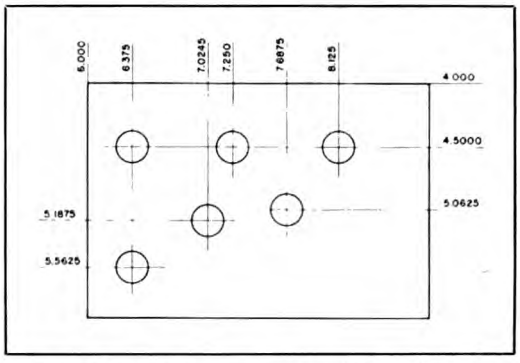


Fig. 148 — Same, with rectangular coordinates.

designate. A simple example is the best description.

Fig. 147 shows a conventional drawing of a typical Jig Borer job. Dimensions are shown in heterogeneous fashion, some referred to the edges of the piece, some from one hole to another. After strapping the work to the table, we can find the location of the upper and left-hand edges with respect to the spindle. The zero brackets and dials may be loosened and set to any figure within a full inch. They need not necessarily be set to zero, see pages 126, 177 and 179.

Let us assume for the moment, however, that the dials are set to zero, and that the longitudinal scale on the table is set to 6.000″, and that the cross scale, on the base is set to 4.000″, when the respective edges of the work are aligned with the spindle. The figures 4.000″ and 6.000″ are immediately written on the drawing, on lines brought out from the edges.

By calculating, adding, or subtracting the dimensions on the original drawing, we find coordinates for the hole centers, Fig. 148. Lettering may be done on the original drawing, or on a new sketch made for the purpose by tracing or carbon-copying.

The coordinate location idea is a continuation, to completion, of the process described in the second chapter under *Laying Out*, page 20 *et seq.* In that case, the die block was accurately squared up and lines laid out on it were all referred to the edges. In the Coordinate Location System, all dimensions are referred to perpendicular intersecting imaginary zero lines.

The positions of the zero lines are different in different makes of Jig Borer, depending upon locations of scales and directions of travel. The Moore Jig Borer is so arranged that the zero lines are along the upper and left-hand edges of the drawing. Increases in dimension run in the same directions as in reading, to the right and down the page.

Operators should not be confused because the directions of increase on the *scales* are not, in both cases, the same as the directions of increase in *coordinates.*

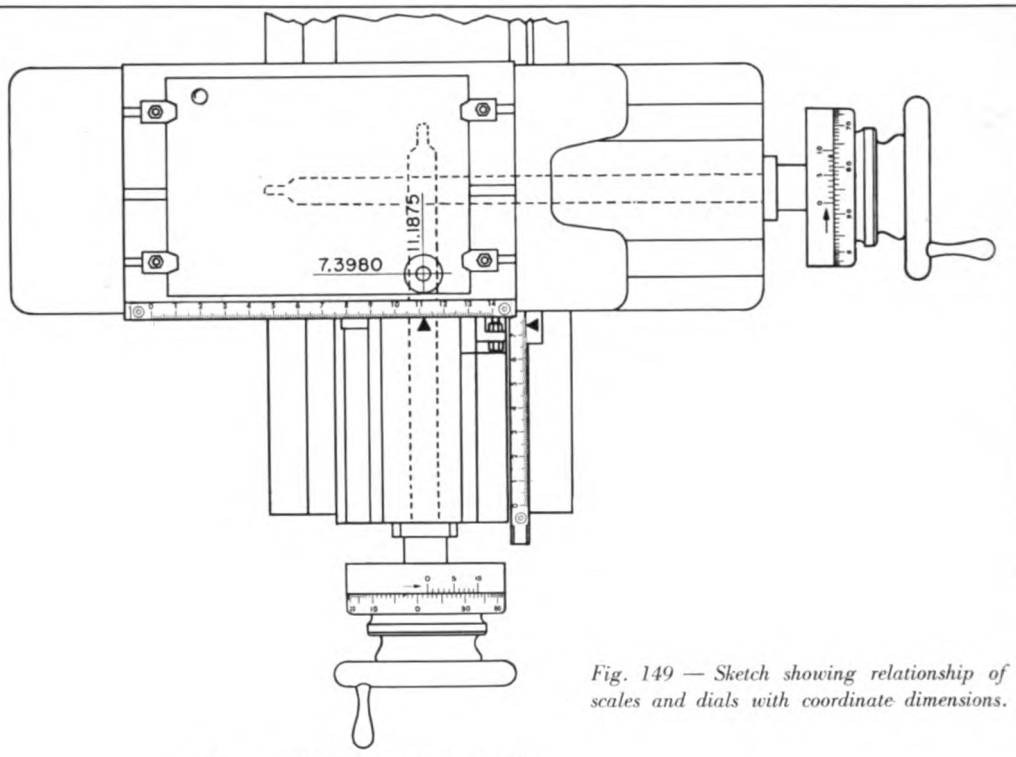


Fig. 149 — Sketch showing relationship of scales and dials with coordinate dimensions.

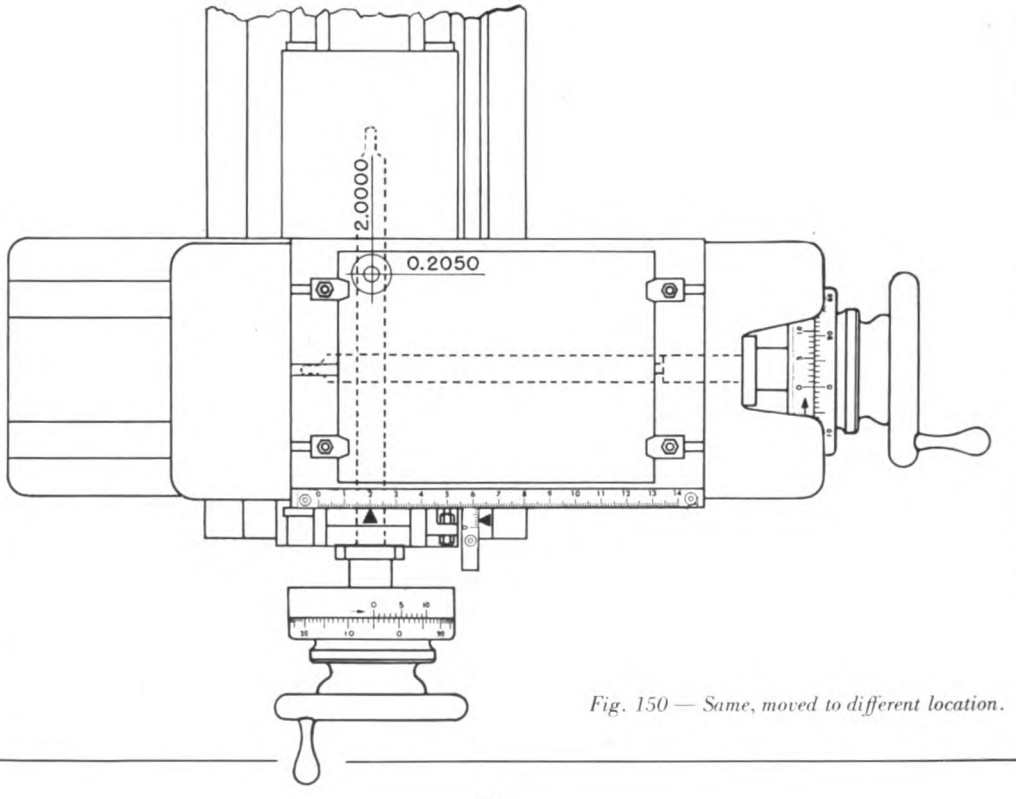


Fig. 150 — Same, moved to different location.

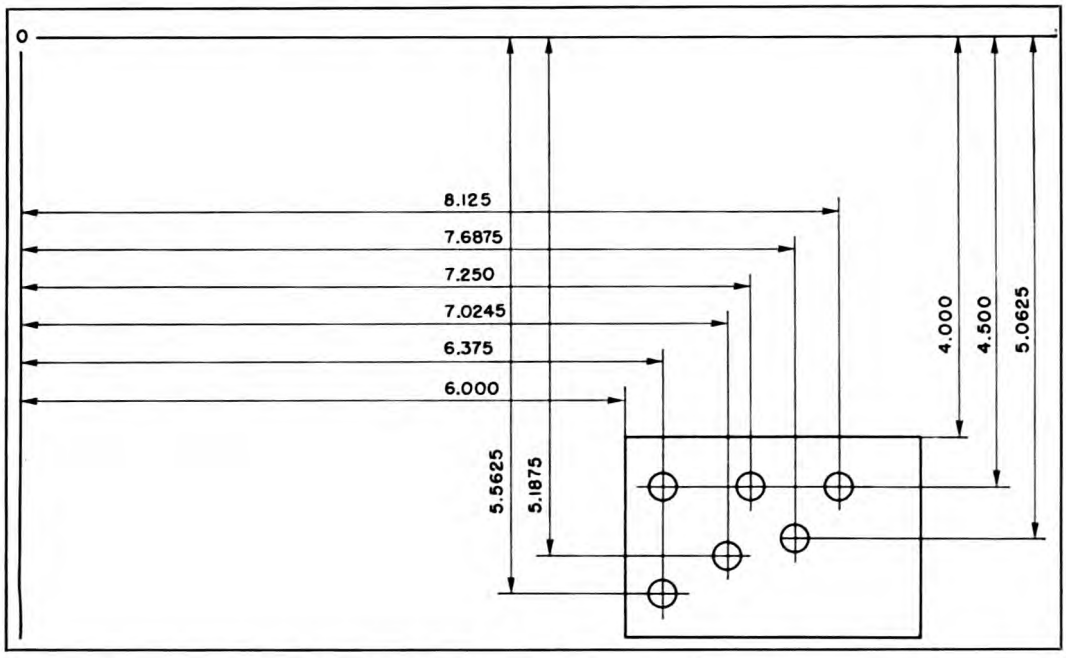


Fig. 151 — Coordinate dimension lines continued to zero lines.

The difference exists because the longitudinal scale, mounted along the front edge of the table, moves with the table, whereas the cross travel scale, mounted on the base, does not move with the cross slide. Instead, a zero pointer, mounted on the cross slide, moves along the scale.

The scale readings on the longitudinal scale, therefore, increase in the same direction as the coordinates, while those on the cross travel scale increase in the opposite direction from the coordinates.

Figs. 149 and 150 clarify the correlation between the coordinates as shown on the drawing and the positions of the scales and dials. These illustrations are shown to dispel operator-confusion. Actually they need not be remembered. All that is necessary to be remembered is that the zero lines run along the *top* and *left-hand* edges.

The form of coordinate drawing shown in Fig. 148 is preferred and strongly recommended by the Moore Company, because of the disadvantages of most other methods.

For example, a commonly used method is that of expressing distances in regular dimensional form, Fig. 151, all dimensions being referred to zero lines.

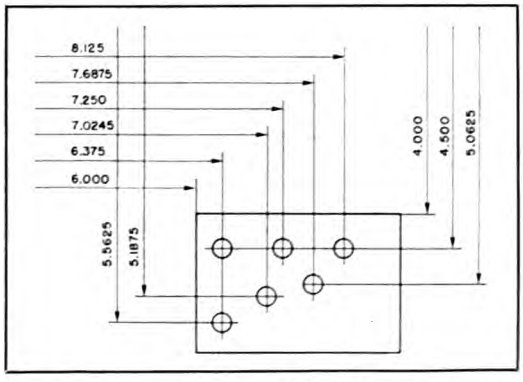


Fig. 152 — Same, with part of line left to imagination.

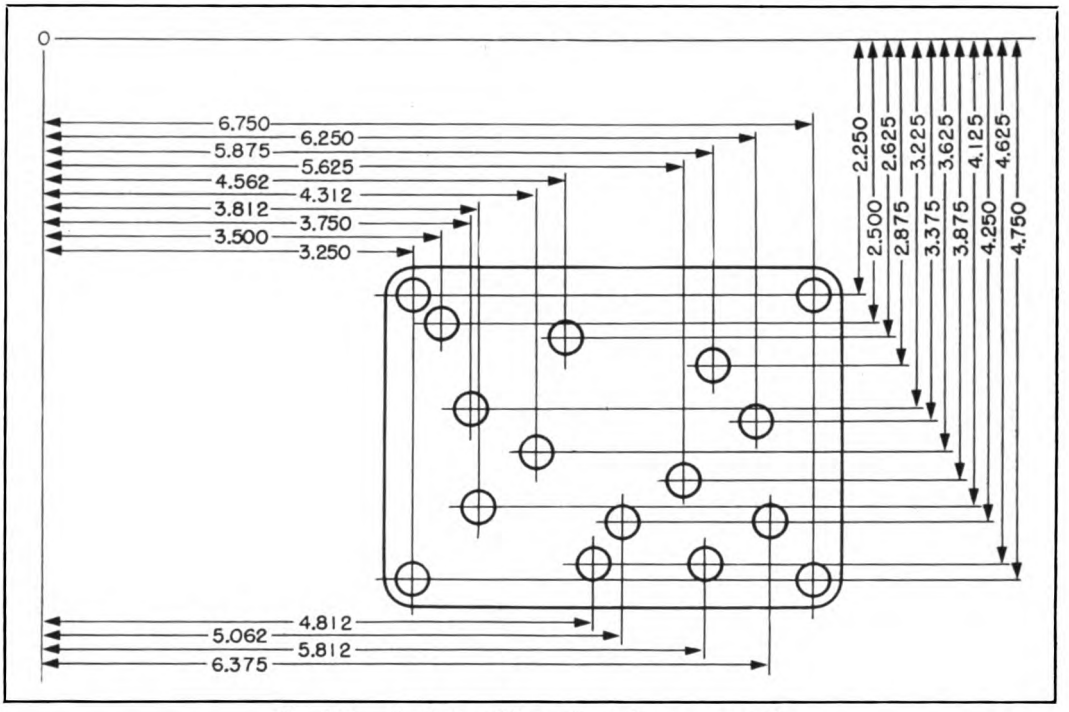


Fig. 153 — Confusion of lines when holes are congested.

A variation of this is to omit the zero lines, Fig. 152. This variation is arrived at by the operator after he becomes sufficiently acquainted with the principle that he can visualize the zero lines in his mind without actually seeing them on the drawing.

Both these forms have the disadvantage that the operator's eye must travel long distances to find the figure he seeks. This is confusing, especially on a job containing a great many holes close together, Fig. 153.

Another common form consists of a drawing without dimensions, used in connection with a chart, Fig. 154. Holes are numbered for identification and correlation with figures on the chart. This form is confusing for the same reason as the previous three examples.

Operator confusion, in searching for the desired figure, distracts him from his main centers of attention, namely the scales and dials and the action of his cutting tools. The distraction is aggravated when the workpiece contains a large number of holes close together.

To prevent confusion, the original form,

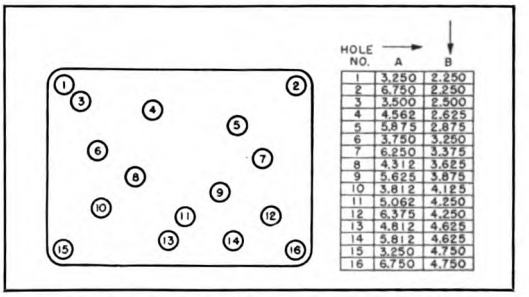


Fig. 154 — Chart method; operator's eye is confused because of lack of visual connection between location of hole and dimension.

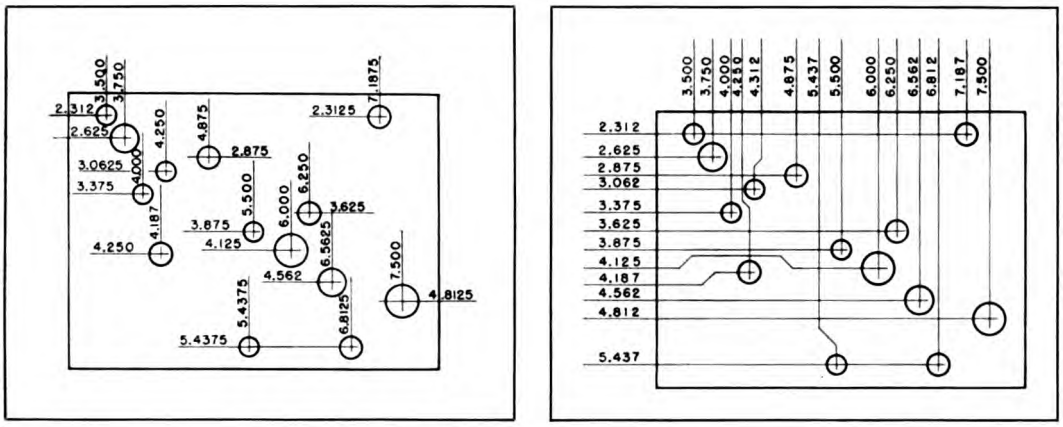


Fig. 155 — Two preferred forms of coordinate dimensions.

Fig. 148, is considered best. This is already regular practice in many engineering offices, and will undoubtedly become a universally accepted symbol for designating Jig Borer Coordinate Locations.

There is a difference of opinion as to the best position for each figure. The writer prefers to place the figure as close to the hole as possible in each case, Fig. 155 (left), to prevent all possible distraction. Others prefer to extend the lines outside the workpiece, Fig. 155 (right), so they may be checked off with a red pencil, in sequence, as various operations on each hole are performed.

Some objections to this follow:

1. The eye must follow lines through longer distances.

2. Operations on holes are not usually performed according to the sequence of the increase in dimension. It is impossible to do this in *both* directions, at any rate. It frequently happens that several holes may be on the same line in one direction, but obviously cannot be on the same line in the other direction.

3. Many operations are performed on each hole, see also pages 108 and 132, necessitating a great many check marks, especially if there are several holes on the same line.

4. Holes in increasing coordinate sequence may be of different sizes. The writer prefers to do the same operation required on all holes of one size before changing tools to perform similar operations on holes of other sizes. In general, it is least confusing to keep the figures as close to each hole as possible. However, the best method is usually determined by conditions met.

Polar Coordinates, or Angular Dividing of Circles — Polar coordinates (angle and distance) are usually employed only when holes are located about a single circle. The biggest job in connection with the setting of polar coordinates is figuring all the angles, especially when there are a good

many holes in the circle. 360° must first be divided by the number of holes in the circle to find the angle between two adjacent holes, and this angle successively added. In the case of a number of holes unevenly divisible into 360° this angle must be figured within small limits, since any error, being continually added, will produce a substantial cumulative error, Fig. 310.

Pre-figuring Coordinates — To save operator's time and secure the greatest capacity from the Jig Borer, the coordinates for each job should be calculated and checked by the Engineering Department before the job is handed to the operator. It is not difficult to correlate the relationship of the pre-calculation with the scales and dials on the machine; Engineering may assume any zero within its range. When the workpiece is strapped to the table, the operator sets his scales and dials to the proper position for the starting point designated.

The starting point is not necessarily zero, nor any even inch. A previously-bored hole, dowel, two edges of the workpiece, or a pair of intersecting lines may be picked up. Scales and dials are then set to whatever coordinates may happen to designate the position of the starting point.

This feature is especially advantageous to companies employing both the Moore Jig Borer and the Moore Jig Grinder. Holes bored in the Jig Borer may be employed as starting points when the job is set up for Jig Grinding without the necessity for recalculating the coordinates. Scales and dials may be set to the same coordinates previously employed in the boring, see also Fig. 254.

Circular Dividing and the Woodworth Tables — Calculation of rectangular coordinates of holes on a circle, or of the angles required for polar coordinates, especially if the circle is divided into a large number of divisions, is a considerable task. To facilitate this calculation, W. J. Woodworth and J. D. Woodworth have prepared tables, see section starting on page 255. These tables give directly the angle to any hole on an evenly divided circle, also factors by which rectangular coordinates may be readily calculated, up to 100 divisions.

Time Estimating — The best guide to time-estimating Jig Borer work is experience. The same may be said for other machine tools of all kinds with this important exception: While time estimates for production machines are usually based on a mathematical calculation of cutting speeds and feeds, those for the Jig Borer are made by mental comparisons with other similar jobs. On regular production machines, quantities are large enough to justify the expense of extensive calculations. On the Jig Borer, however, the nature of the work precludes this.

The Jig Borer, in general, is used on three classes of work:

1. Toolmaking. Tool parts are usually made one at a time, or, at least, in very limited quantities. These parts vary widely from one to the next. Sometimes there may be a great many holes in a single piece. If holes are small and arranged in regular rows or straight lines (as in Fig. 156), they may be bored in as little as one or two minutes per hole. Ten to fifteen holes in a single plate, if not over ¼″ to ⅜″ in diameter, and the stock not more than ⅜″ or ½″ thick, may be finished in around ten minutes per hole. A single large hole in a complicated box jig, on the other hand, is a different matter. Setting up, picking up location, and boring the hole may consume two to three hours.

2. Small-lot production, to eliminate the expense of making a jig. Many times the accuracy requirements are loose enough to permit spotting and drilling. The work may be held in the Jig Borer in a simple fixture, or even in a vise, Fig. 105. The work is done quickly in such a case. Extensive mathematical calculations are unjustified; time consumed in calculating might exceed the time required to do the work.

3. Either small-lot or large-quantity production, where the required tolerances or finishes, or both, are such as to be unattainable with drills or reamers in a jig. Some materials, such as aluminum, do not take good finishes in this manner. Others, such as cast iron, bronze, and steel, require heavy cutting pressures, with the result that the best accuracy cannot be obtained in drill jigs. All these jobs are best done in the Jig Borer. In these cases, especially on large quantities, the time estimate might be approached from a mathematical viewpoint. The intangibles of high accuracy and high finishes, however, usually preclude its feasibility even in such cases. If it were not for these considerations, jobs of this kind would be performed in drill jigs in the first place.

For these reasons, it is considered that the best guide to time-estimating a new job is to make a mental comparison with some other similar job. Examples, in subsequent pages, of work done show reasonable time estimates or actual time consumed for each job.

15 Holes in 15 Minutes — The fifteen-hole plate, Fig. 156, is an excellent example to illustrate the unusual speed of table settings by means of accurate lead screws in the Moore Jig Borer. The fifteen 3/32″ diameter holes in each of these plates

Fig. 156 — 15 holes in 15 minutes, spotted, drilled and reamed to ±.0002″.

may be spotted, drilled, and reamed in fifteen minutes, floor-to-floor time.

This does not include accurately picking up an edge; the piece is merely strapped to the table and lined up by eye. A rigid spotter or center drill, with a cutting diameter .010″ or .015″ smaller than the finished hole, is the first tool employed. Since the plate is only 1/16″ thick, the spotter is fed all the way through, the tapered part going deep enough to make a conical recess at the top of the hole about the same size as the finished hole.

Now, instead of changing cutting tools, the table is moved to the position of the next hole, and so on, until *all* holes are spotted.

The next operation is drilling with a .089″ drill, also successively, one hole after another.

After all holes have been thus spotted and drilled, a 3/32″ reamer finishes them to size. In place of a reamer, on this small size, a drill may be used. If the corners are slightly broken with a fine stone, it makes a free-cutting reamer, and will cut a good, round hole.

This job admittedly favors the lead-screw principle. Holes are .500″ apart in both directions; exactly five turns of the screw moves to the next hole in each case, and settings are made with utmost convenience and rapidity.

Regardless of this, however, it must be conceded that the lead-screw principle in itself is fast and efficient, since on this job a total of forty-five table settings plus forty-five individual cutting operations are performed within fifteen minutes.

This method, moreover, is reasonably accurate, especially in thin stock, up to 1/8″ or 3/16″, when hole sizes do not exceed 3/16″. Inasmuch as the first cutting tool is rigidly held, it produces a countersunk hole directly under the spindle. The subsequent drilling and reaming are accurately guided by the countersink and remove so little stock that the positions of the holes are undisturbed. Hole locations in the plates are undoubtedly within ±.0002″ to ±.0003″. A boring cut prior to the reaming operation, consuming about five minutes per plate, would bring the accuracy within ±.0001″ or ±.0002″.

Operational Practices, General—Details of operational practices are best shown by examples. Before proceeding to these, however, a few general remarks are in order. Pages 15-17 show three fundamental steps in hole location:

1. Location
2. Cutting
3. Inspection

These steps are all efficiently performed on the Moore Jig Borer. In general, the following sequence of operations is recommended. Although all operations may not be specifically repeated in the examples subsequently shown, they are understood and adhered to wherever possible:

1. True up starting point, or points, with respect to spindle. Set scales and dials to proper figures. This establishes position of starting point and all holes in the Coordinate Location System.

2. Spot positions of all holes *lightly* with center drill. This operation is insurance against errors in dial settings, see No. 3.

3. Make new settings for all holes, respotting with center drill to sufficient depth to provide guide for subsequent drilling. At this point, operation No. 2 may appear superfluous. It is definitely advantageous in preventing the most common errors in making settings, those of misreading the scales by an even .100″, or misreading the dials by .010″. When the work is touched by the center drill to perform operation No. 3, an error made on operation No. 2 is instantly detected, since the center drill will not align with the original spot. Errors as small as .002″ or .003″ are readily detected. Any misalignment warns the operator to check his setting.

Operations No. 2 and No. 3 should be performed with rigid center drills, held in drill chuck or collet. This procedure contrasts sharply with that described in Fig. 24. The difference is that, at this point, the *spindle* axis is the controlling factor for hole location; Fig. 24 described a case where the *prick-punch* mark was to be the controlling factor and errors of spindle misalignment were to be avoided to as large an extent as possible.

4. Rough-drill and rough-bore all holes. Stock removal should be accomplished wherever feasible by drilling or sweeping with sweep tools. These tools absorb side thrusts within themselves, and do not unduly strain the spindle. Single-point boring, when taking heavy cuts, exerts heavy side loads on the machine spindle, while drills and sweeping tools exert only torsional and axial loads. When drilling large holes, increase the size in steps of ¼″, instead of attempting to force large drills directly through the work. Large drills, such as ¾″ or 1″, do not cut freely at the center, due to the thick web connecting the flutes.

5. Go back and check the original setting of the work (operation No. 1) to make sure it has not shifted during the roughing operation. On especially accurate work, make sure at this time that the workpiece has cooled to room temperature before making this final pickup.

6. Make the final finish-boring cuts in each hole. Finish-boring small amounts is unlikely either to warm the workpiece unduly or disturb its setting. This procedure has advantages in many directions.

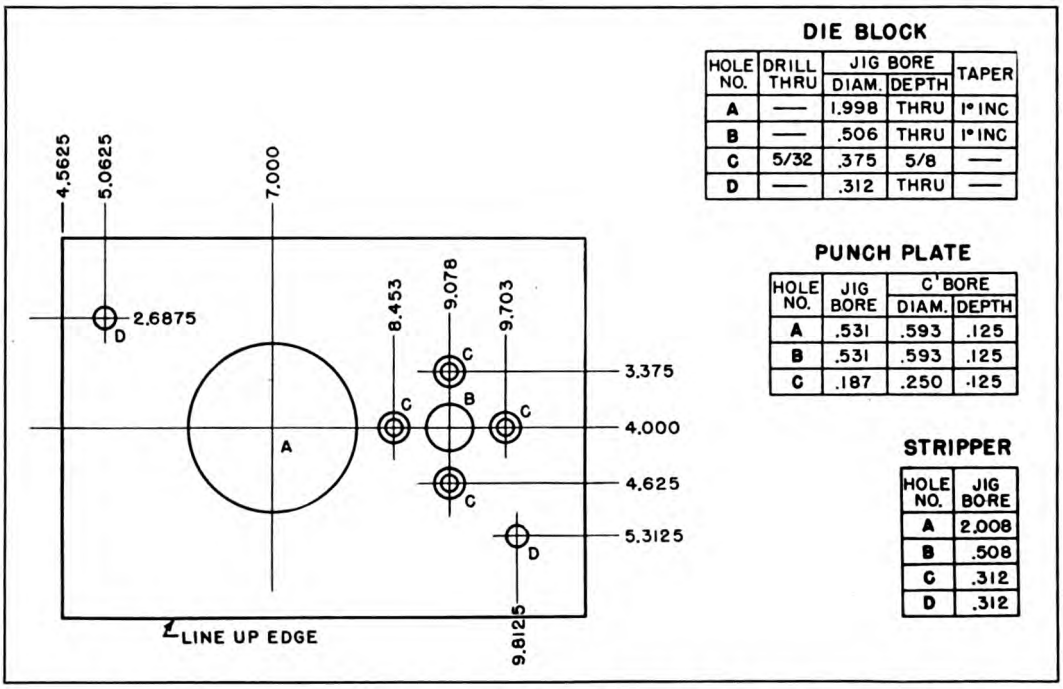
7. Inspect all holes bored for location. This should be done while the workpiece is still strapped to the table. Make a fresh pickup of the starting point, then make a fresh setting for each hole. Indicate each hole from the spindle. Operators may ob-

ject that inspection should not be performed in the same machine as that in which the work is done. Sufficient experience with this method usually gives confidence, however, that the Jig Borer is as dependable for this as any other shop standard. See also pages 235 to 246.

Operational Practices by Example — The first example is the same die described in Figs. 5, 6, and 7, with the original assumption that extreme accuracies are not required. Boring may be done to high accuracies in the Moore Jig Borer, of course, but the die will not be ground; it will be accepted as it comes from heat-treating.

There is one problem the Jig Borer does not yet efficiently solve — the taper, or draft, in the blanking hole and the center piercing hole. Attempts made to design tools for boring tapered holes have proven largely unsuccessful in one respect or another. Usually they are large and heavy, and the cutting tool overhangs so far from the spindle that much of its rigidity is lost. Loss of rigidity results in chatter and ridges in the work. A real challenge exists to designers of boring heads to develop a tool without these handicaps.

It should be pointed out at this time that a new machine, the Jig Grinder, also developed by the Moore Company, solves this problem (Chapter VI). The Jig Grinder is capable of grinding the draft, and, in cases where the Jig Grinder is available, it is unnecessary to worry about boring tapered holes in the Jig Borer.



DIE BLOCK

HOLE NO.	DRILL THRU	JIG BORE DIAM.	JIG BORE DEPTH	TAPER
A	—	1.998	THRU	1° INC
B	—	.506	THRU	1° INC
C	5/32	.375	5/8	—
D	—	.312	THRU	—

PUNCH PLATE

HOLE NO.	JIG BORE	C'BORE DIAM.	C'BORE DEPTH
A	.531	.593	.125
B	.531	.593	.125
C	.187	.250	.125

STRIPPER

HOLE NO.	JIG BORE
A	2.008
B	.508
C	.312
D	.312

Fig. 157 — Coordinate layout drawing for Jig Boring all parts of die in Figs. 5 and 6. Stripper locating dowel holes are included to assure good perpendicularity.

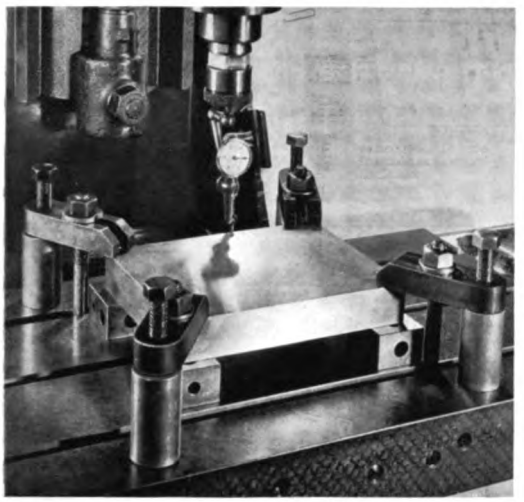


Fig. 158 — Indicating edge of die block parallel with table travel.

For the present, however, we are assuming that the Jig Grinder is not available, and that the taper will be bored in the lathe, before hardening the die. Two methods of approach are feasible:

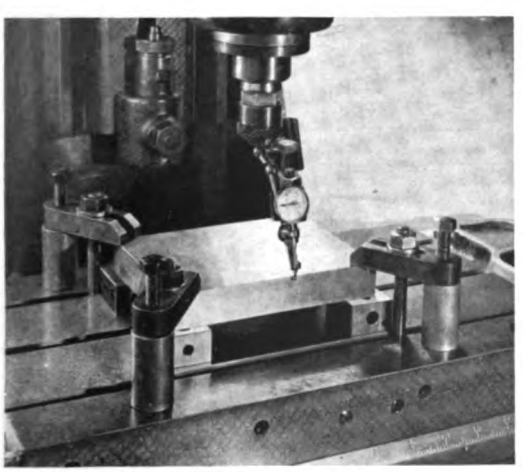
1. Since no accurate relationship to the outside of the die is required, the main hole could be finish-bored to size and taper in the lathe and this hole employed as the reference, or starting point, to which all other holes are related. After Jig Boring all other holes, the die must be put back on the lathe faceplate and the center piercing hole trued up and bored to taper.

2. The locations and sizes of all holes may be established in the Jig Borer, the draft in the main blanking hole and the center piercing hole being subsequently bored in the lathe.

The second procedure will be illustrated. The first requirement is a coordinate drawing, Fig. 157.

One side of the die is indicated true, Fig. 158, to permit sides of die to establish direction of stock feed.

Although not necessary, it is comparatively quick to establish the center of the die block as the center line of the piercing and blanking holes, Fig. 159. This will assist us later in making the stock guides. Ground flush with the sides of the die, and of equal width, they automatically centralize the blank in the scrap.



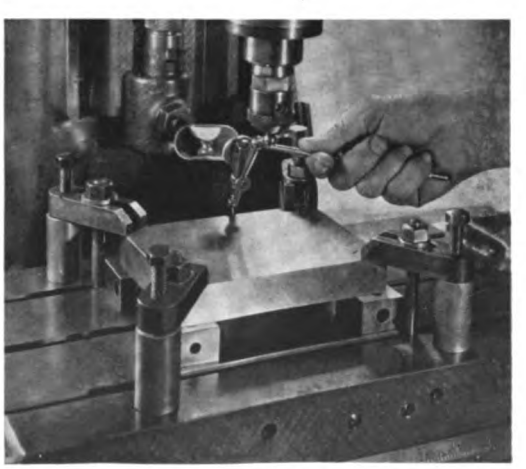


Fig. 159 — Indicating both sides of die block to centralize with spindle.

Fig. 160 — Picking up end of die block with line finder.

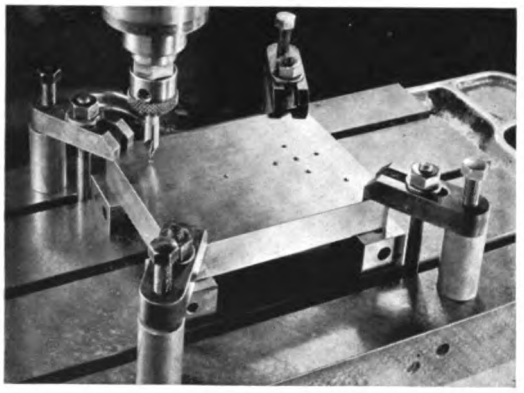
Endwise location of the holes in the die block is of no particular importance; the Line Finder is sufficiently accurate, Fig. 160.

Procedure on pages 70 to 71 should be followed. First, spot all holes lightly, then retrace all settings, and spot all holes deeply, Fig. 161. Drill the main blank hole up to 1″ with drills, then sweep nearly to size with sweep tool as in Fig. 120.

As an alternative, a rough layout, as in Fig. 9, might be made, and a large amount of stock removed by drilling in a large drill press or radial drill, Fig. 162, before setting up the job in the Jig Borer.

Drill the center piercing hole up to $^{17}/_{32}$″ or $^{39}/_{64}$″ with twist drills.

Drill the four small piercing holes through with the ¼″ drill, then to the proper depth with a $^{23}/_{64}$″ drill. Square



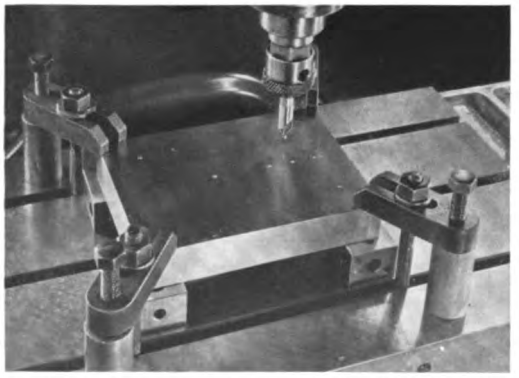


Fig. 161 — Spotting and re-spotting die blocks, good insurance against error in table setting.

Fig. 162 — If desired, large holes may be roughed out in large drill press or radial drill before Jig Boring.

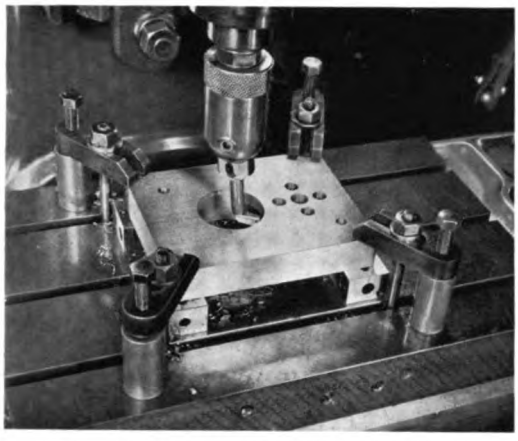


Fig. 163 — Finish-boring blank hole to size.

Fig. 164 — Indicating holes in hardened die block.

up the shoulders with a flat end drill, Fig. 119, also $^{23}/_{64}$".

Check the original location, Figs. 158 to 160.

We are now ready for finishing to size. Lacking reamers for such large sizes, the blank hole will be bored to size, Fig. 163. The other holes may be bored .002" or .003" undersize, then reamed, or may be bored to size.

The die may now be swung up on the lathe faceplate, and the blank hole and center piercing hole successively indicated and bored to taper, as in Fig. 20.

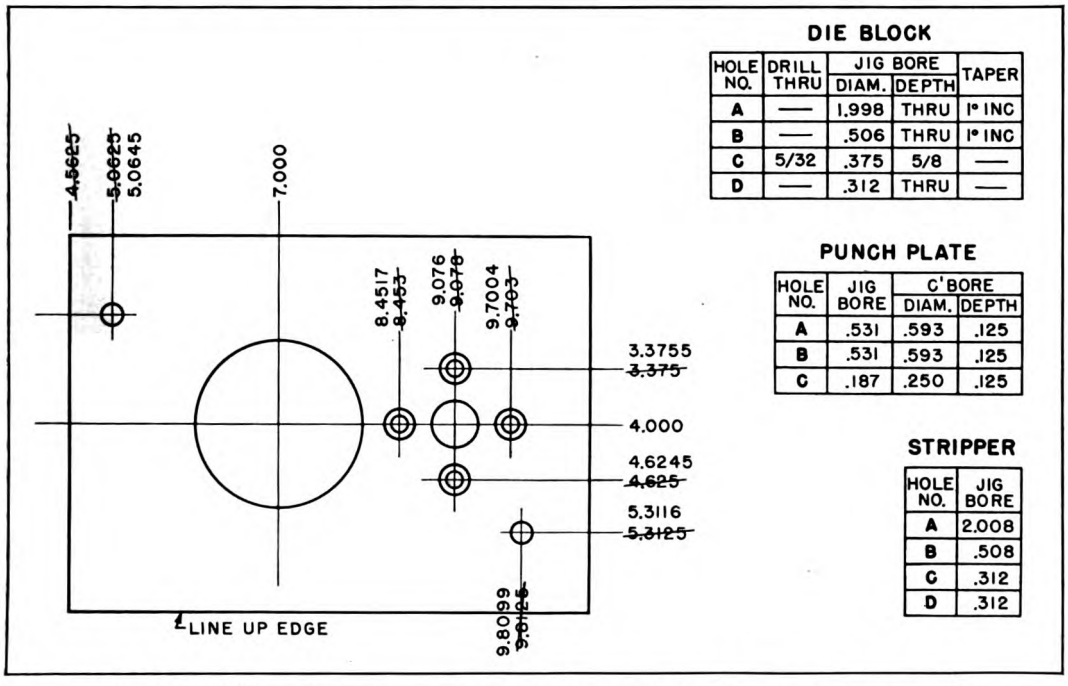


Fig. 165 — Old coordinates crossed out, new dimensions including distortion errors substituted.

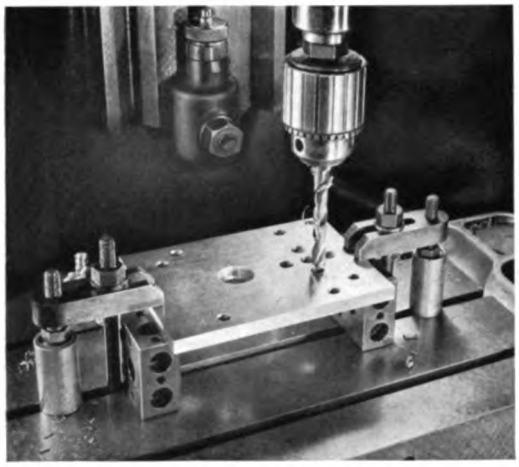


Fig. 166 — Jig Boring stripper to dimensions independently from die block.

Screw and dowel holes are now drilled and tapped, or reamed, as the case may be, and the die is ready for heat-treating.

The stripper and punch plate may not be bored until the die has been heat-treated, since the distortion errors from heat-treating are to be retained.

Not only must the stripper holes be related to each other, they also must be properly oriented to the holes in the die block, when attached to the die with dowels. This may be achieved in either of two ways:

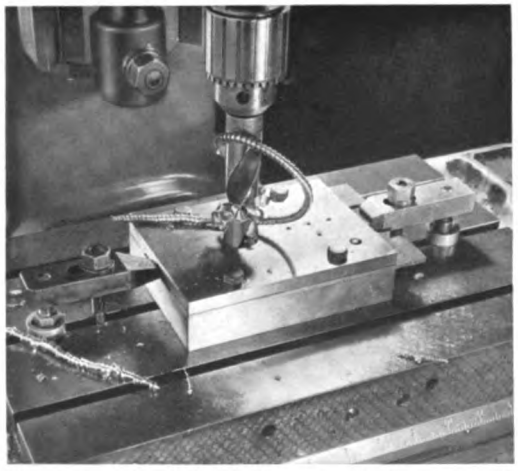


Fig. 167 — Jig Boring stripper attached to die block.

1. By Jig Boring the stripper independently to dimensions, including the dowel holes.

2. By Jig Boring the stripper attached to the die with the dowels.

Method No. 1, Jig Boring Stripper Independently — In either case, a new coordinate layout must be made to include the heat-treating errors. To do this, the die block is strapped to the table, set parallel to the line of the blanking and center piercing holes, and each hole indicated true from the spindle, Fig. 164. The new coordinate locations are then substituted, Fig. 165. Since the stripper is to be Jig Bored independently, Fig. 166, coordinates for the dowel holes are picked up and included on the drawing.

Method No. 2, Boring the Stripper Attached to the Die — This is more commonly employed, Fig. 167. Dowel holes are transferred to the stripper by drilling and reaming before the die is strapped down, and the new coordinates found for the holes, as in Fig. 164. The stripper is now doweled to the die and the stripper holes Jig Bored. Obviously the die must be firmly held, and the stripper held independently, Fig. 167.

After the new coordinates for the heat-treated die are found, Fig. 165, the punch plate may be Jig Bored, Fig. 168. Orientation from dowel holes is unnecessary,

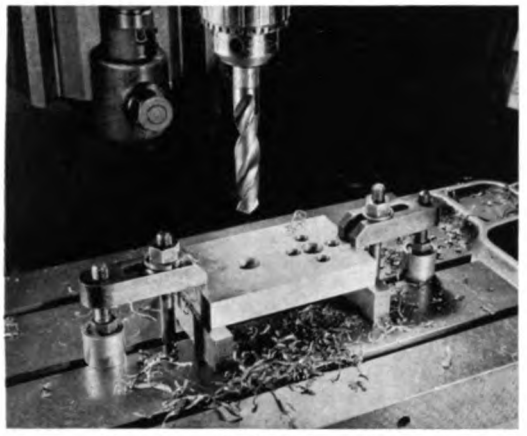


Fig. 168 — Jig Boring punch plate.

since the punch plate is clamped to the punch holder and drilled together after the die has been doweled to the die shoe.

Inspection should be carried out as a regular part of the job as each part is bored. Inspection after heat-treating, of course, is automatic; differences between the new coordinates and the old are immediately noted.

The Jig Borer is also ideal for the job illustrated in Figs. 38, 39 and 40. The requirements should be reviewed. The exact angle at which the template is filed up into the die is not known; yet it is necessary that the group of piercing holes be correctly interrelated, and that they be correctly oriented to the die opening.

The template, of course, must be accurately made, since it is to be used, like a master plate, for final reference of all piercing holes. The template is pushed to the top of the filed die opening, Fig. 169, and the die strapped to the Jig Borer table. The edge of the die block is pushed against the Jig Borer straight-edge, ensuring parallelism of stock travel with the edges of the die.

Each hole is now indicated from the spindle, Fig. 169, and coordinates determined. Addition of stock move to each longitudinal coordinate now determines coordinates for Jig Boring piercing holes,

Fig. 169 — Use of the Jig Borer instead of carrier as in Figs. 38, 39 and 40. Die strapped to table parallel to travel, each hole in template indicated from spindle.

Fig. 170 — After indicating hole in die, table is traversed, amount of stock moved establishing position of each piercing hole.

Fig. 170. After heat-treating, a new pick-up of each piercing hole is made for boring the stripper and punch plate, as in Fig. 164. This, of course, retains heat-treating errors in the die and, therefore, in the piece part.

If desired, heat-treating errors may be corrected by grinding and the die made accurately to dimensions by the method illustrated in Figs. 205 to 209, a tedious, time-consuming procedure, or by means of the Jig Grinder, Chapter VI.

Making Templates — For filing die-opening contours, templates are frequently employed. Blanking dies are filed with a certain amount of taper, or draft, and the template may be inserted in the bottom of the opening before it is filed to size. Visual examination determines the "high spots", these being marked, watched carefully, Fig. 171, and filed until the template, flush with the top of the die, "shuts out light".

The making of the template without a Jig Borer presents a tedious problem. Usually a piece of 1/16" or 3/32" ground stock, strapped to an angle iron, is laid out with a height gage, dividers, and scriber, then sawed and filed to the desired shape, indicated by the scribed lines. The burr thrown up on the edge of the template by filing obscures the lines, rendering them ineffective when approaching size. As a result, means other than visual must be employed for checking the template. Small contours may be projected against a screen in the

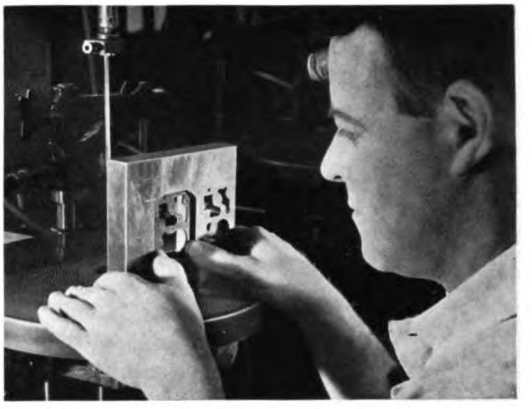


Fig. 171 — Fitting template to die opening.

Fig. 172 — Jig Boring template.

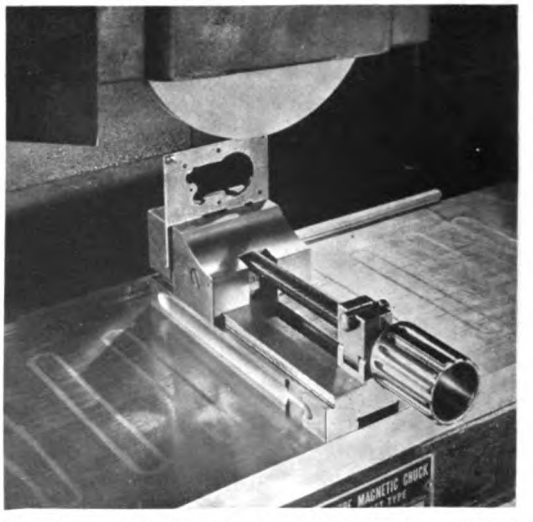


Fig. 173 — Grinding side of template. Size is established by reference to bored holes.

Fig. 174 — Removal of excess stock by band-sawing.

optical comparator; others are laboriously checked with sine bars, toolmakers' microscopes, micrometers, or height gages and indicators.

The Jig Borer can be employed to enormous advantage in the making of templates. Although some exceptional contours may be very irregular, most of them

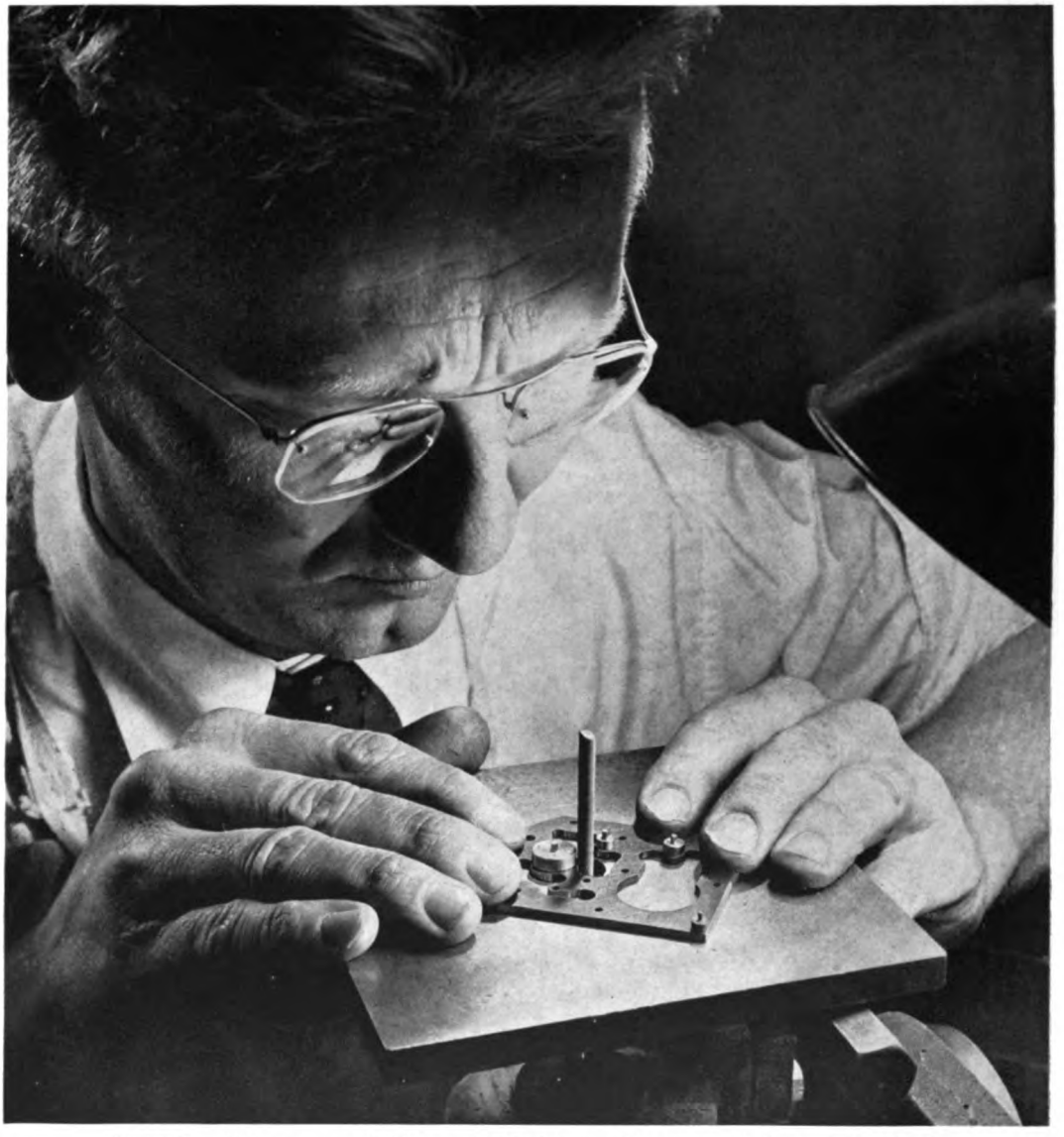


Fig. 175 — Filing contour. Radii are established by watching concentric button in bored hole.

are definite geometric shapes, consisting of straight lines or radii, intersecting or joined by other radii, either internal or external. The Jig Borer is employed as the basis of measurements, Fig. 172. Reference points take the form of bored holes. Holes may be bored at the centers of external radii, later to be joined by straight lines by grinding, Fig. 173. Internal radii may be bored directly to size in the Jig Borer, Fig. 172. Excess stock is removed from the template by sawing, Fig. 174. Radii may be filed to size with concentric buttons, Fig. 175.

Fig. 176 — "Pin cam," or spiral crown gear, mounted on rotary table for angle and distance settings.

Models and Experimental Work — In addition to its usefulness in toolmaking, the Jig Borer fills an important place in modelmaking and experimental work. Some experimental work is frequently required before the engineering on a device is completed. After computation of the engineering, a model is usually made to engineered dimensions for proof against errors. In either case, hole location is one of the problems encountered.

In some cases, the parts are merely employed as parts of a working model; in others, they might be used not only as parts of the working model, but also as masters or prototypes from which duplicates are made.

The aluminum pin cam, Fig. 176, presents an interesting example of this. The plate shown in the photograph is employed as a master. Duplicates of this are made in quantity by a plating process.

Although arbitrarily named a "pin cam" by the manufacturer of the device on which it is used, the part is, in reality, a 32-pitch crown gear, with the teeth on a spiral-shaped path, to provide a variable ratio between itself and the meshing pinion. Many combinations of ratios have been made, some with approximately logarithmic rates of change, others with respect to complex curves involving many variables, such as are required in gunfire computations.

The tooth section is illustrated in Fig. 177. As may be seen, two alternative methods present themselves for the fabrication of the conical tooth: to locate a series of holes, into which to insert tooth-shaped pins, or to machine the tooth out of the the solid stock. The second course was finally adopted as the most practical. Fig. 177 shows not only the tooth, but the Jig Borer cutter employed for making the

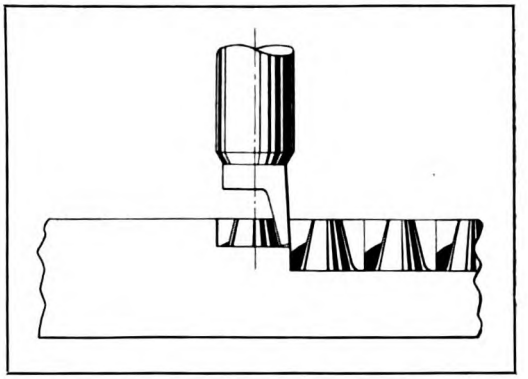


Fig. 177 — Detail of conical gear tooth and cutter used to produce it.

tooth. The cutter is plunged down into the solid stock, forming the tooth and the root in a single cut. Pitch diameter is maintained by means of the positive stop.

An interesting sidelight is the fact that three men worked on this job, one to read off the polar coordinates (angles and distance), one to make rotary table settings, and the third man to make the table settings and operate the cutter. When there are a great many settings on a particular piece, such as this one, it is occasionally of great advantage for a man to assist the operator in reading the coordinates. Shifting the eye from a chart to the dial, then to the rotary table, then to the cutter, becomes tiresome for one operator.

There is a wide variety of types of these pin cams. While some may have only 200 pins, others have as many as 800. It was found that three men working on an 800-pin cam could fabricate it completely in three working days elapsed time, or about 1.8 minutes per tooth.

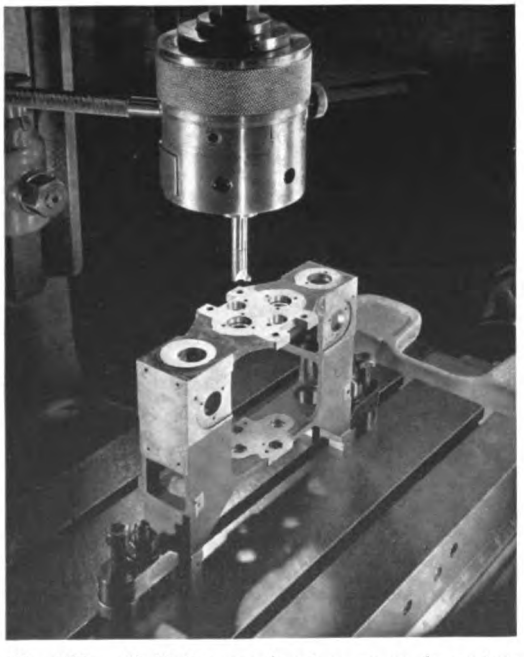


Fig. 178 — Multiplier gear housing, set up for various machining operations.

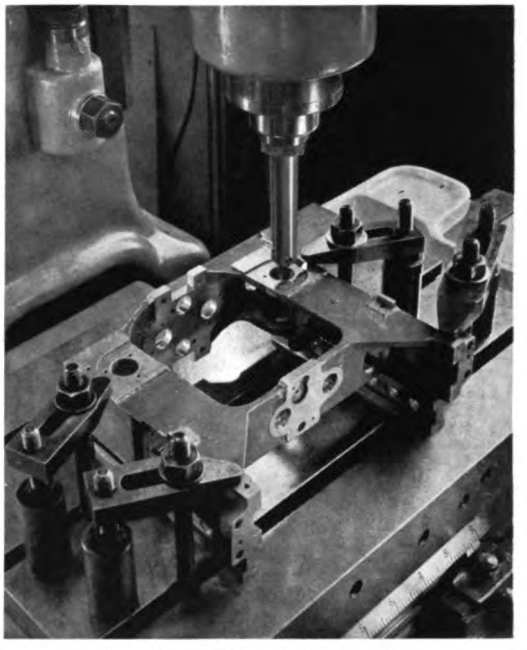


Fig. 179 — Same, another position.

The aluminum multiplier gear housing, Figs. 178 and 179, is a run-of-the-mill experimental job. An aluminum alloy casting, this piece is made on a one-at-a-time basis, as a component for a working model. Many different operations are performed—boring, milling, drilling, tapping, spotfacing.

Most of the flat surfaces are milled in the Jig Borer. An ordinary tool bit, held in the boring chuck or in one of the boring bars, is satisfactory for this. The operation is like "fly-cutting," or single-point milling. Operations of this kind are not con-

sidered abusive to a good Jig Borer. If handled with reasonable care, light milling cuts should do the Jig Borer no harm. There is a tremendous advantage, in fact, in being able to do milling and other light operations in the same setup as the boring, since it eliminates the necessity for making separate setups in separate machines.

Fig. 178 recalls a prior discussion of boring heads, page 102. The "precision" head, in use here, is of the adjustable-while-running type. Outfed while running, it is being employed to face the bottom of the ball-bearing pockets. Although this head is of highly reputable make, it has the disadvantage of being somewhat large and heavy. On light machines this promotes vibration and chatter, especially if heavy work is attempted. It handles light cuts, such as those here shown, without difficulty, and proves very helpful in squaring shoulders.

The Jig Borer work on this piece consists substantially of the following:

Material, cast aluminum alloy

25 surfaces milled to ±.001″

16 holes bored to location within ±.0005″, and to size within ±.0001″

10 faces for ball-bearing seats, bored and held to depth within ±.001″

10 small holes for dowel pins and other small sliding parts, held to size and location within ±.0005″

30 small screw holes, drilled (tapped by hand)

Holes in this piece go in from every face; it is necessary, therefore, to make six setups, one on each outside face.

Time per piece: 18 hours.

The Jig Borer as a Production Machine — The scope of the Jig Borer is by no means limited to tool or model work. It assumes an important position, in addition, as a production machine, or jig eliminator. There are two conditions where this especially applies:

1. When the quantity of parts to be produced is too small to warrant the cost of making a drill jig. As a matter of fact, in many cases, production can be achieved fully as rapidly in the Jig Borer as in a drill jig. If high accuracies are not required and, if the piece can be firmly held, the holes can be spotted and drilled without boring within tolerances comparing favorably with those held in jigs.

2. When the required accuracy is such as to be unobtainable in a drill jig, regardless of cost. Slender, fragile pieces, for example, may not be able to withstand the heavy cutting pressures applied by drills or reamers without distortion and resultant loss of accuracy. Some types of material, especially aluminum, do not take smooth finishes from drills or reamers, but spall and pick up. At best they require heavy cutting pressures. Single-point boring, on the other hand, especially on finish cuts, may be performed with light cutting pressures, and produces good finishes. Use of

carbide cutting tools, properly engineered for the job, permits operational speeds far in excess of those feasible with drills and reamers. These production operations, therefore, are not necessarily more expensive than if performed in drill jigs. There are many cases, in fact, where jigs are nearly impossible to use.

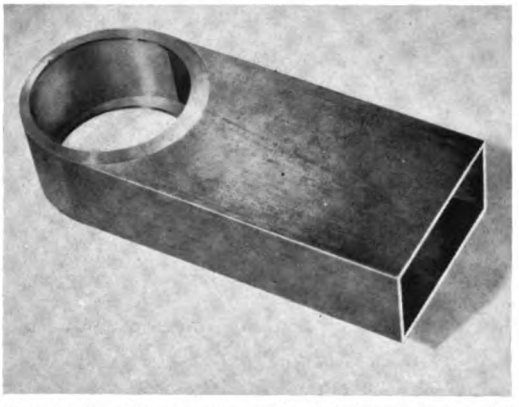


Fig. 180 — Brass wave guide, fabricated by brazing semi-circular piece to rectangular tube.

An example of this is the thin rectangular brass shell, Fig. 180. A semi-circular brass piece is brazed into the end of the tube, then machined. 6,000 pieces were required, machined as follows:

Diameter of top hole, 2.562″ + .002″ − .000″.

Diameter of bottom hole, 2.250″ + .002″ − .000″.

Inner surface of semi-circle machined to a radius of 1.419″ + .001″ − .000″. Center of this radius is offset .062″ forward from the centers of the top and bottom holes.

Outside top and bottom surfaces swept to an overall dimension of 1.480 + .000″ − .003″. This is accomplished with a special hollow-ground sweep tool, ground on both top and bottom surfaces, inserted into its holder above or below the work. The same tool is inserted in the holder inside the workpiece for sweeping the inside faces of the holes.

Since the semi-circular surface does not comprise a full half-circle, a problem is encountered in measuring the 1.419″ radius. This is facilitated by inserting and clamping a filler piece, or dummy, into the open end of the tube, extending in far enough to be bored at the same time as the 1.419″ radius. This piece provides a measuring surface. It may be used over and over again.

The job outlined above poses a considerable problem. The two hole diameters and the sweeping of the outside surfaces *could* be done in a drill jig, with boring bars. A drill jig, however, would have serious disadvantages. Means for clamping the workpiece against heavy cuts would crush it and distort it. To provide sufficient supporting surfaces, it would entirely encompass the work, rendering it bulky and inaccessible for tool setting and checking sizes. Boring the eccentric semi-circular portion would be a practical impossibility.

The Jig Borer, therefore, was selected as the means for machining it, Fig. 181. The setup is simple. Holding mechanisms leave the work accessible, and the .062″ offset is provided by moving the table.

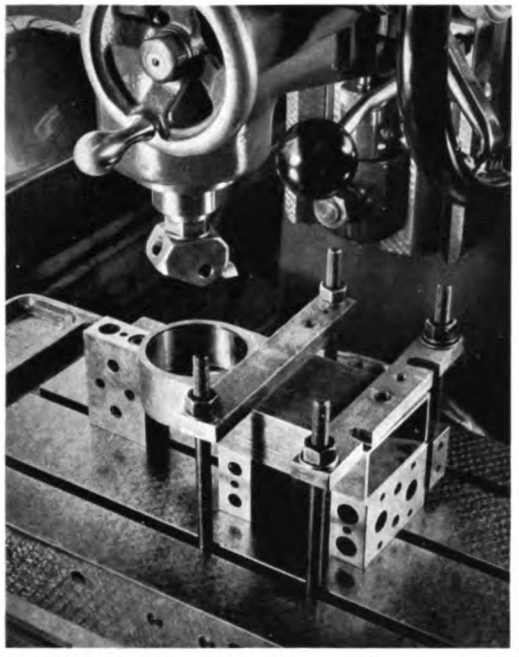


Fig. 181 — Jig Borer setup for machining wave guide.

Time required per piece: 1.6 hours, floor-to-floor.

The irregular-shaped slide bearing casting, Fig. 182, provides an excellent example of small-lot production Jig Boring. Since the quantities required are only five or ten pieces per lot, it was felt that it would be too expensive to make the drill jig either large enough to provide proper support or sufficiently accurate to drill and ream the two .375″ slide holes. These must be parallel to each other and to the base of the casting within small limits, and accurately positioned with respect to the slot.

Accordingly, a combination drill jig and Jig Borer fixture was provided. Four 9/32″ screw holes, a ¼″-20 tapped hole, and the cross holes in the small ears are drilled in the jig.

The jig is then screwed to the Jig Borer table and employed as a fixture for boring the two .375″ holes in the arms. The workpiece is oriented to and supported in the fixture by means of plugs through the previously-drilled holes, Fig. 183, and clamped by ordinary parallel clamps. It was not considered advisable even to go to the expense of quick-acting clamps.

The fixture is picked up by means of an edge finder against the locating face and a construction hole, Fig. 183, directly in line with the locating boss.

It takes about fifteen minutes to set up this fixture. After setting it up, the two holes are spotted, drilled, and single-point bored to size in eight hours per piece.

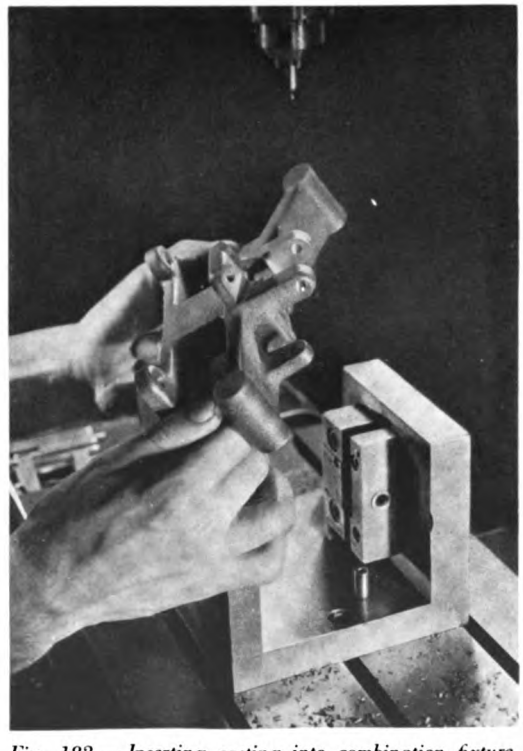


Fig. 182 — Inserting casting into combination fixture.

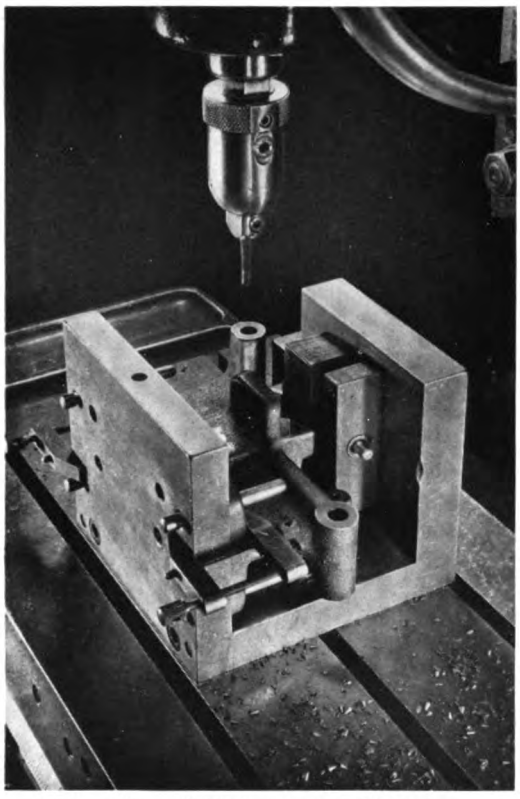


Fig. 183 — Jig Boring the two .375" holes.

The high-speed multiple tapping head bodies, Fig. 184, present a unique Jig Boring job. Every one is a special job, necessitating one-at-a-time fabrication; yet in a sense, it is a production job. The manufacturer of these tapping heads maintains a stock of unbored bodies, bearings, bushings, gears, spindles, chucks and other parts required in their assembly. These parts are all standardized. Each head is special only with respect to the locations of the spindles in the body and is built especially for the multiple tapping of screw holes in some particular component.

After determining the necessary locations of the spindle and calculating gear centers, the manufacturer takes a body out of stock, sets it up in the Jig Borer, and bores all the holes to size and location.

All hole sizes are also standardized; each is bored to take a standardized bearing or bushing. To facilitate sizing, the tool bit collet, Fig. 112, is employed. One collet is left set at all times for roughing and another for finishing each hole size. After drilling the hole, the proper collet is inserted and the hole automatically brought to size.

It is a justifiable boast of the manufacturer, and a major sales promotional argu-

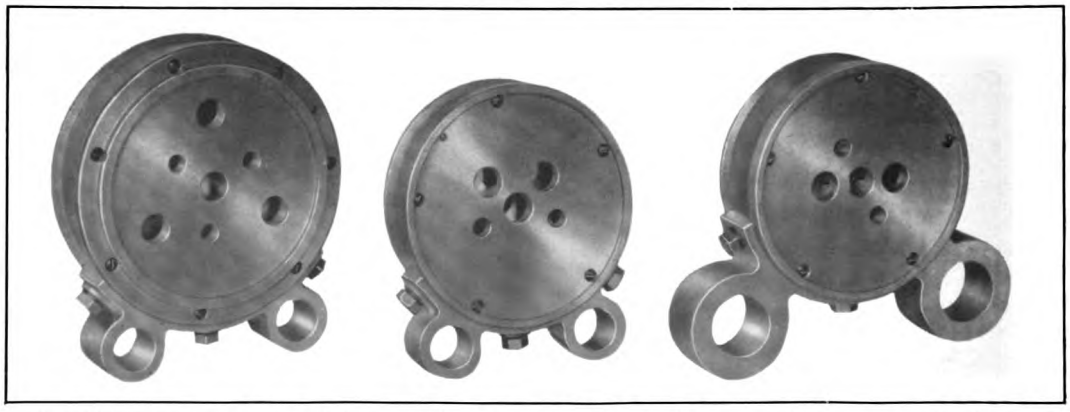


Fig. 184 — Each of these multiple tapping head bodies is different with respect to location of spindles. Manufacturer stocks standardized heads, spindles, gears and bushings. Head is Jig Bored and quickly assembled.

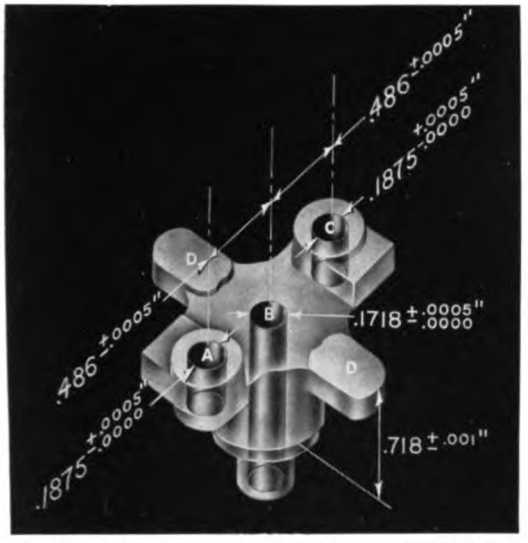


Fig. 185—Aluminum stud Jig Bored on production basis.

ment, that he can ship a special tapping head, worth hundreds of dollars, within 24 hours after receipt of order!

The Jig Borer is not limited to small-lot production merely as a jig eliminator. It is often employed on large quantities, especially where required accuracies or finishes cannot be obtained from a drill jig. The aluminum stud, Fig. 185, is an example. Although the required quantity, 5,000 pieces, would be sufficient to absorb the cost of a drill jig, it was not felt that it would meet accuracy requirements:

Locational tolerances of holes A, B, and C, ±.0005″.

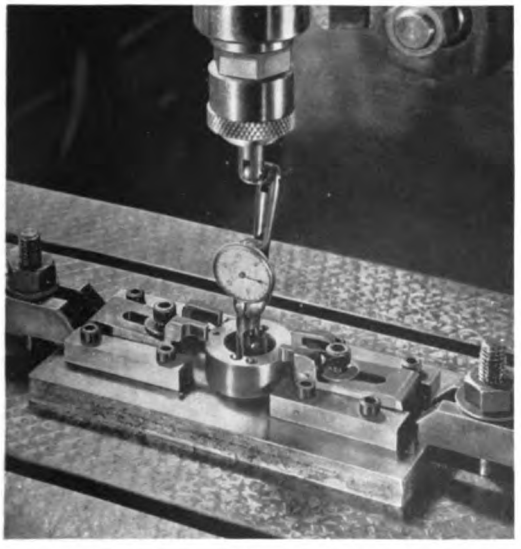
Size tolerances of holes A, B, and C, +.0005″ −.0000″.

Must be parallel within .001″ checked on plugs 1″ long.

Pads milled to correct height, .718″, within ±.001″.

All holes, including those to be Jig Bored, are first drilled in jigs, .012″ being left for Jig Boring. The back end, including the back face of the pads and the small diameter, is turned in a lathe, providing work points.

A simple fixture, Fig. 186, set up and indicated central with the spindle, locates the workpiece centrally and vertically.



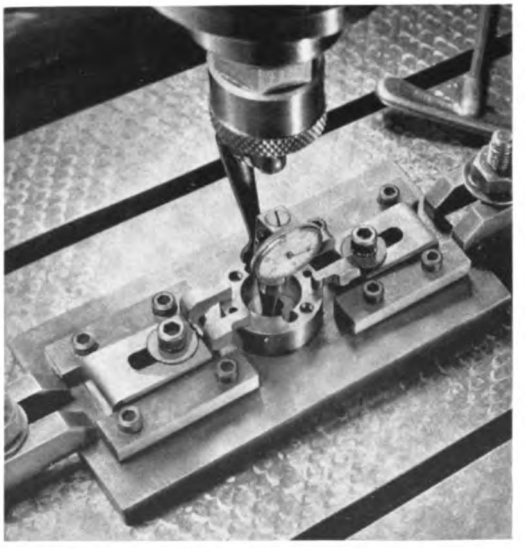


Fig. 186 — Two views of fixture to hold aluminum stud, Fig. 185.

Orientation of the piece in the fixture is achieved by plugging pins through the drilled holes into similarly-located holes, after which the clamps are tightened, and the plugs removed.

After locating the piece in the fixture, movement of the table by the lead screws aligns the spindle with the proper hole for boring, Fig. 187. Since two hole diameters are required, two boring chucks are employed, one set permanently for the .1718″ diameter, and one for the .1875″ diameter. The two chucks are interchanged between hole settings more quickly than size adjustments may be made. Tungsten carbide tool bits are used for both these cuts. In this non-ferrous material (aluminum), the tools wear very slowly, holding their adjustment over long periods of time. This permits the simple changing of chucks to bore the correct hole sizes. The square tool bit collets might be used instead, Fig. 112. One pass down and up brings the holes to size within the required tolerances.

After boring the holes to the required sizes, a collet containing a two-flute endmill is inserted into the spindle in place of the boring chucks, Fig. 188. The quill housing is lowered to the pre-set micrometer stop, the quill extended to the limit of the pre-set vertical stop, and the pads milled. Vertical heights of the pads were held to .718″ +.0000″ −.0005″, well within the required tolerances.

Total time, bringing three holes to size and location, milling pads to correct height, floor-to-floor time: 6 minutes.

Occasionally, only some few holes in a workpiece require such high accuracy as to necessitate Jig Boring, while others may

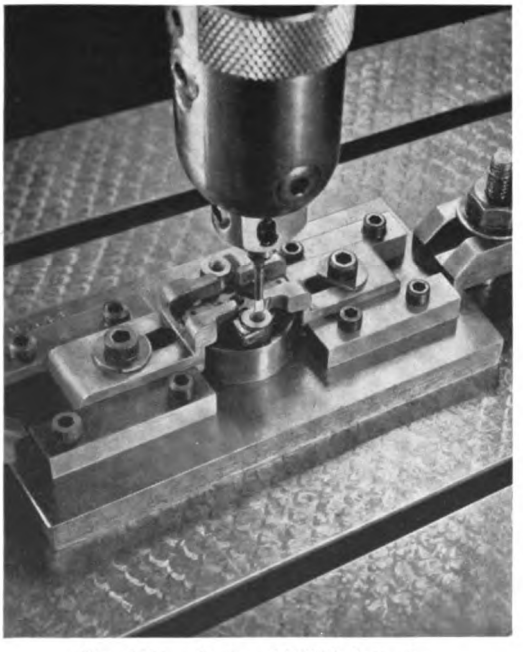


Fig. 187 — Boring .1875″ hole to size.

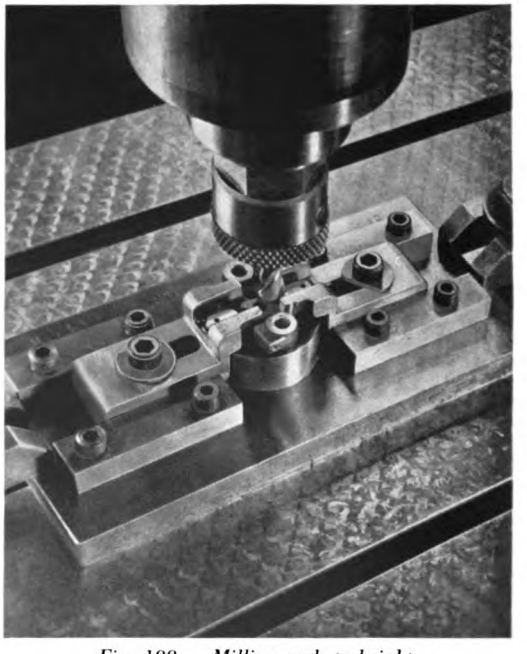


Fig. 188 — Milling pads to height.

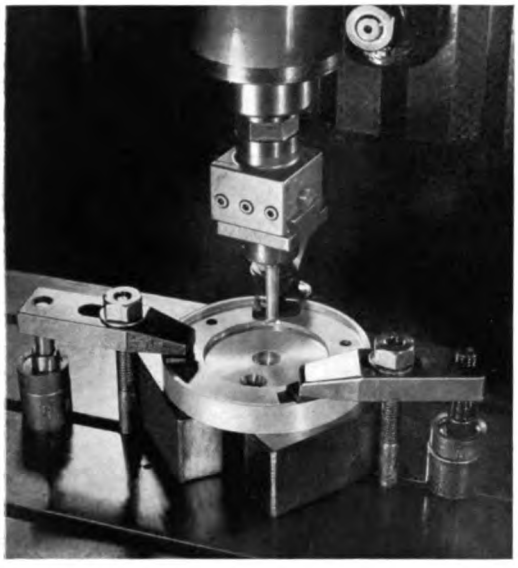


Fig. 189 — Jig Boring first four holes in aluminum pump cover.

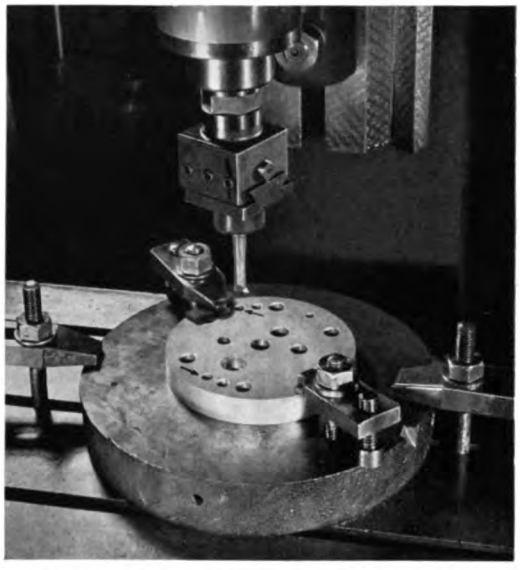


Fig. 190 — Same, setup for counterboring hole on reverse side.

be jig-drilled. The aluminum pump-cover, Figs. 189 to 191, is an example. The blank is first turned in the lathe, the Jig Boring being subsequently performed in three steps:

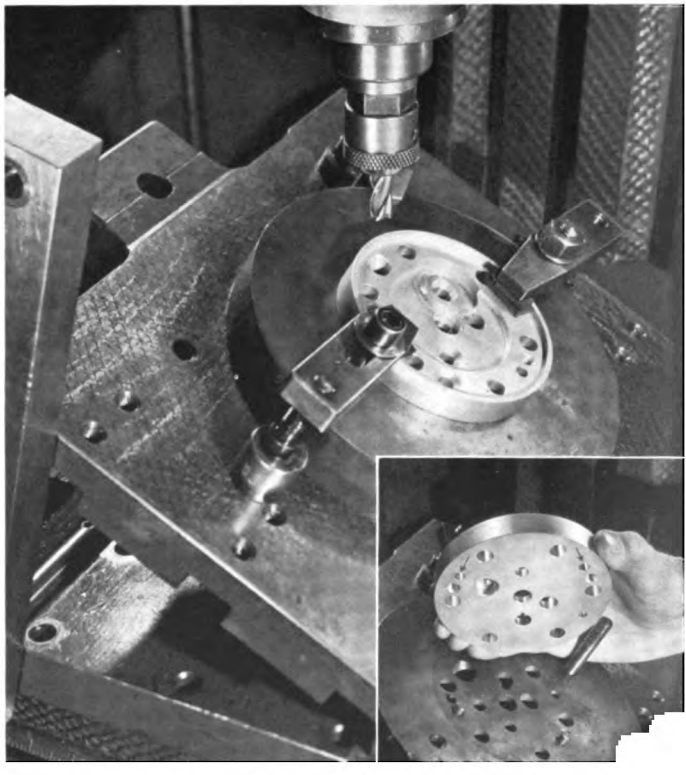
1. The first operation consists of boring the four holes, Fig. 189. The center hole (.4075″ −.4085″ diam.) goes through, approximately ⅜″ deep, and is counterbored .560″ −.561″, .310″ −.320″ deep. Two locating holes (.234″ −.2345″ diam.) are bored through, a depth of ½″. The fourth hole (.3745″ −.3755″ diam.) is bored through and countersunk 60° × .520″ ±.010″ diam. Excellent finish is required.

Time for this operation: 25 minutes per piece.

2. After all other holes are jig-drilled, the piece is again brought to the Jig Borer, and put in a low-priced fixture, Fig. 190. Locating is achieved by means of pins in the locating holes, indicated by arrows. One hole is counterbored by single-point boring. Time for this operation: 7 minutes per piece.

3. The fixture is next mounted on the micro-sine plate, the workpiece being again

Fig. 191 — Setup for milling angular elongated slot. Note setting bar for micro-sine plate.



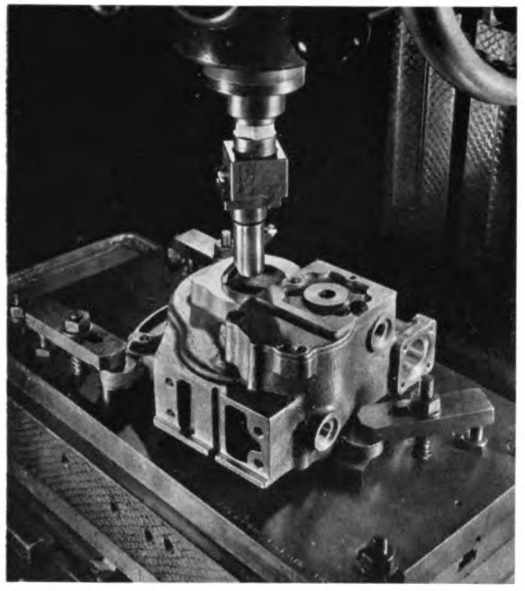


Fig. 192 — Boring main hole and hole in cover. Note false lugs for locating and clamping.

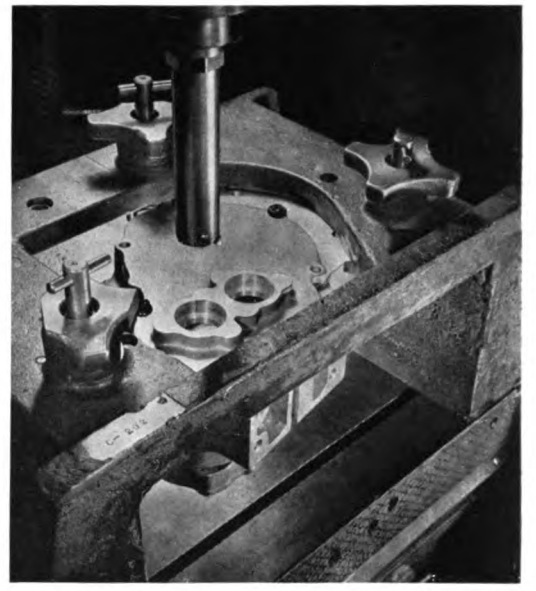


Fig. 194 — Line-boring cover and housing, held in fixture by false lugs.

Fig. 193 — Rough-boring holes inside main housing.

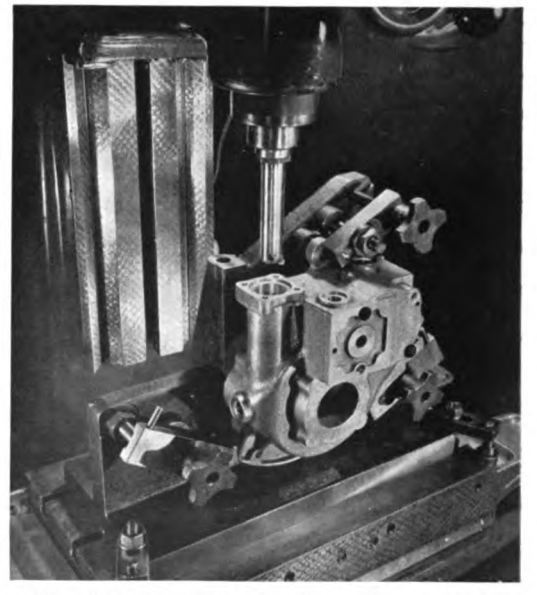


Fig. 195 — Jig Boring deep hole and counterbore.

reversed and located on the same pins, preparatory to milling the angular slot, Fig. 191. Two end mills are employed for this, one for roughing, and one for finishing. To size the radii, the spindle is set to the desired center, and the finishing end mill plunged straight down through the hole. Flats on the sides of the slot are generated by advancing the table .010″ at a time, and plunging the end mill through.

Time, foregoing operation: 7 minutes.

The above time estimates are average, based on lots of 300 pieces. In each case, after setting up and becoming accustomed to the part, operators found that the estimates could be bettered by 15 to 20%.

An interesting development on this job is the setting bar for setting the micro-sine plate. Insertion of gage blocks and clamping the table are somewhat tedious, especially when they must be done repeatedly between operations. The ends of the gaging plugs are ground to a standard size and fastened to the sine plate so they protrude beyond the sides of the plate. A bar, bored to a calculated distance between the holes and bushed to take the wear, is slipped over the ends of the plugs, establishing the correct angle.

Considerably more extensive tooling is required for Jig Boring the radar drive gear housing, Figs. 192 to 195, necessitating fixtures for each major operation. This job is also interesting from another standpoint: Three locating lugs, visible in Figs. 192 and 195, are cast onto the main casting. These are machined with the largest flat surface, bored to the average location of the rough casting, and are subsequently used as locating points for the remainder of the boring. After the housing is finished, these lugs, having served their purpose, are cut off and destroyed.

With the exception of these reference lugs, the Jig Boring is broken up into three major operations:

1. Fig. 192, boring a 2″ ±.015″ hole through the casting, counterbored to 2.2495″ +.0005″ −.0000″ diam. by .692″ +.003″ −.000″ deep, and boring a hole in an attached cover. The hole in the cover is ⅝″ ±.015″ through, counterbored to .750″ +.002″ −.000″ diam. × .406″ ±.005″ deep.

Time for this operation: 25 minutes each.

2. For the second operation, the piece is clamped upside down in a large, open-topped fixture, Figs. 193 and 194. In this operation, it is necessary to bore a blind hole and counterbore in the casting body in line with holes and counterbores in the cover, Fig. 194. The holes in the casting are roughed before the cover is attached, then finish line-bored with the cover on. Also, counterbores are bored in the cover. Diameters of holes and counterbores are held to diameter +.0005″ −.0000″. Depths of counterbores are held to +.005″ −.000″, referred to top of cover.

Time, this operation: 35 minutes each.

3. The third operation comprises the boring of a hole 1.005″ diameter, 3½″ deep, topped by a counterbore 1$^{13}/_{32}$″ ±.015″, .093″, ±.005″ deep, Fig. 195. The bottom face of the counterbore and the 1.005″ diameter are joined by a $^{5}/_{64}$″ radius.

Time, this operation: 15 minutes each.

The above estimates are based on lots of 1000 pieces, not running continuously, but including breakups. Floor-to-floor time per piece runs 15 to 20% lower.

Jig Boring of the Fuel Injector Pump

adapter, Figs. 196 to 201, is of considerable interest, due to its complexity. Both the rotary table and micro-sine plate are employed, to generate compound angles. The center hole and major casting dimensions are turned in a lathe.

The first Jig Borer setup is shown in Fig. 196. The housing is roughly centralized with a plug, checked and finally set by indicating. Many operations are performed in this setting:

1. A .937″ diameter hole is roughed, and the counterbored recess finished to diameter within +.0005″ −.0000″, to depth within ±.002″.

2. A flat surface surrounding this hole and the center hole is milled.

3. A radial clearance around the .937″ hole is milled.

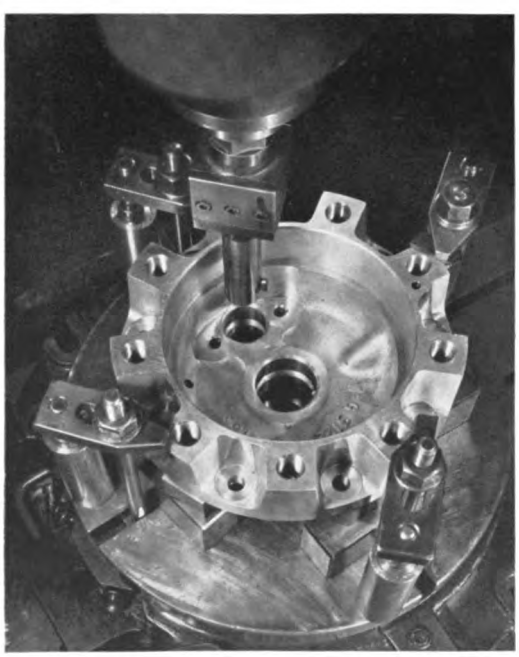


Fig. 196 — First Jig Borer setup for fuel injector pump adapter.

4. Two holes are drilled, to be tapped.

5. Drill and spotface nine .344″ × .813″ holes.

This consists of three operations, viz: spot, drill, end mill.

Two of the holes are also accurately bored to provide pickup points when the piece is subsequently turned over, Fig. 198.

6. Drill, bore, undercut, tap, seat, nine holes, section of which is shown in Fig. 197. There are eight separate operations in each of these holes. Only the top end of the hole, down to the .281″ diameter is finished in this setting. Tools used in this hole are left set, performing the same operation on all holes successively. Drill one .188″ blind oil hole.

Time, above setup and operations: 9 hours.

The second Jig Borer setup is shown in Figs. 198 to 201. The workpiece is mounted on the rotary table, in turn on the micro-sine plate. The piece is picked up and oriented by indicating the center hole and

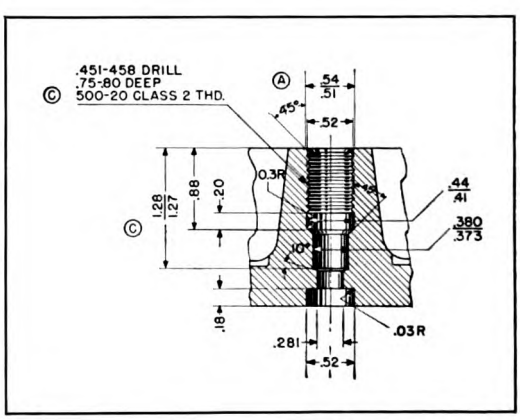


Fig. 197 — Section through tapped hole, showing undercut and seats.

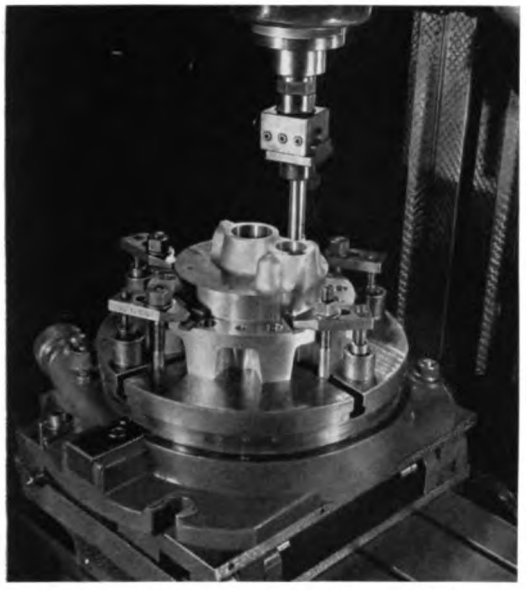


Fig. 198 — Finish-boring .937″ ±.0005″ hole.

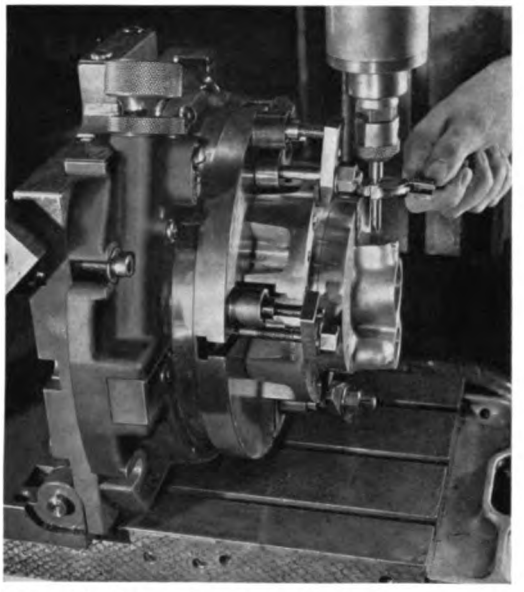


Fig. 199 — Pipe-tapping for oil fitting.

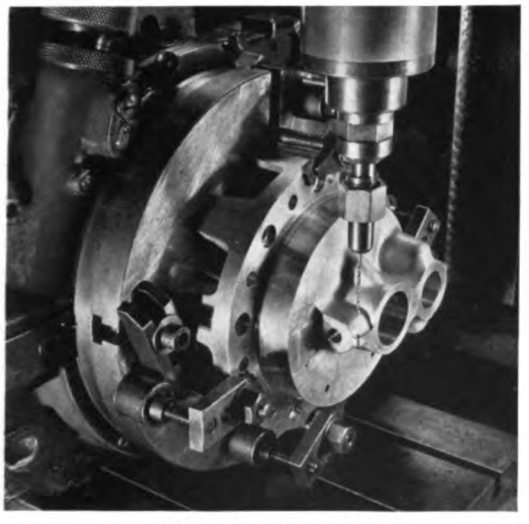


Fig. 200 — Drilling wire hole.

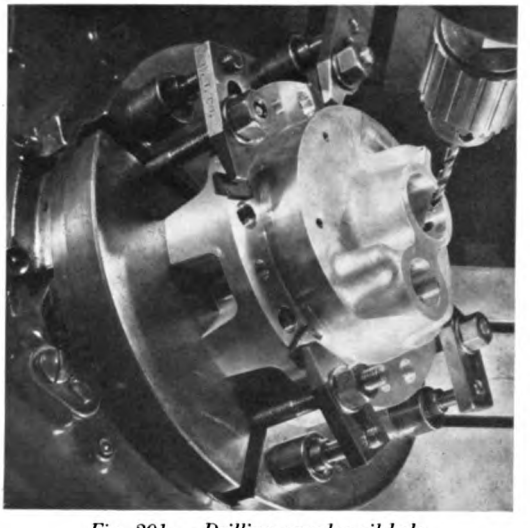


Fig. 201 — Drilling angular oil hole.

two of the .344″ holes bored in the first setup. Operations are as follows:

1. The .937″ hole is finish bored, Fig. 198, to ±.0005″.

2. The .52″ × .18″ counterbore is put into drawing, Fig. 197.

3. Two 3/16″ holes are drilled.

4. Pad face is milled preparatory to subsequent drilling and tapping.

5. The micro-sine plate is now raised to 90° with the setting bar, Fig. 199, and a hole drilled and pipe-tapped. This hole is also continued through to the .937″ hole.

6. A small hole is drilled into a boss near the pipe-tapped hole, Fig. 200, for wiring the pipe fitting.

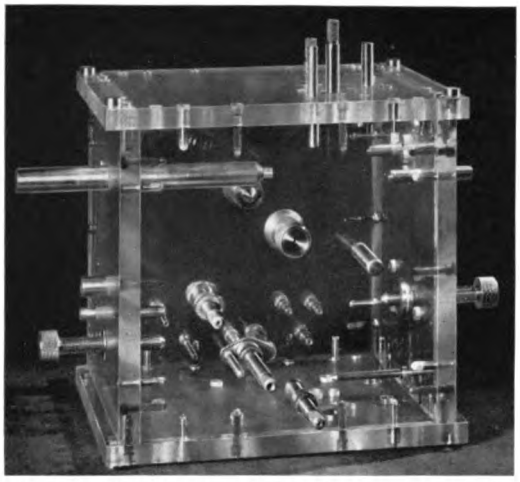


Fig. 202 — Transparent plastic sighting fixture containing bushings and sighting plugs corresponding to the correct locations of holes and machined surfaces.

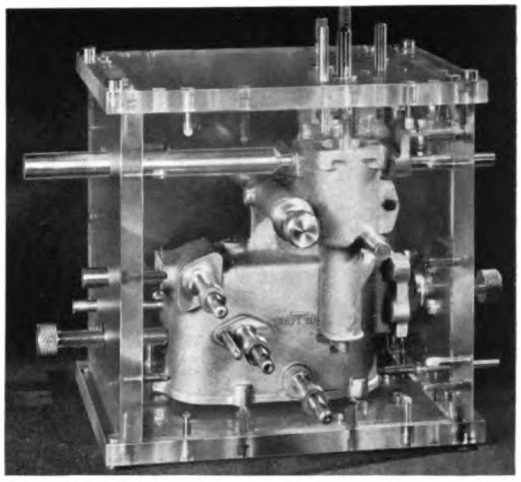


Fig. 203 — The eye can readily judge whether casting is properly oriented to suit the best average of all bosses and machine cuts.

7. The micro-sine plate is now tipped back to 44°, Fig. 201, and a .188″ oil hole drilled to meet the .188″ blind hole drilled in the first setup, Fig. 196.

Time, second setup and operations: 6 hours per piece.

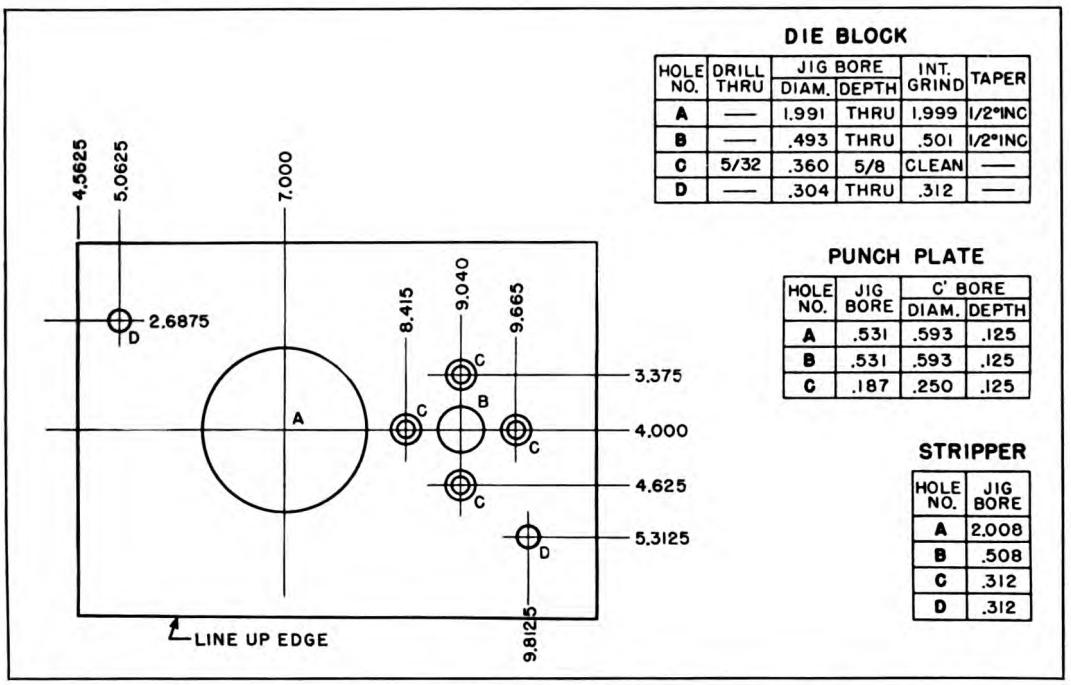
The first machine cut taken on a complex casting is of major importance, since it is subsequently employed as a reference from which all other machine cuts and holes are located. It is necessary that holes be bored in the centers of bosses, and that other machined surfaces clean up.

To insure this, the entire casting may be laid out before the first cut is taken, or, as an alternative, immediately afterward, with the intention of repeating the cut, correcting it to the average of the errors in the casting.

This tedious and costly cut-and-try procedure is eliminated by the device in Fig. 202, a simple transparent plastic sighting fixture. It contains bushings and sighting plugs, corresponding to the correct locations of holes and machined surfaces. When the workpiece is inserted, Fig. 203, the sighting plugs are pushed against the casting. The eye can readily judge whether the piece is properly oriented.

It is estimated that this ingenious solution eliminated about eight hours of layout time on each casting, in favor of a fifteen minute visual inspection.

Establishing Locations Prior to Grinding — The ever-increasing demand for high accuracies in tools and other hardened steel manufactured parts has necessitated the finding of a method for correcting hole location *to dimensions*, by grinding. Difficulties encountered in buttoning and the limitations of the master plate method eventually led to the development of the Moore Jig Grinder, Chapter VI. In the interim, however, a method was evolved



DIE BLOCK

HOLE NO.	DRILL THRU	JIG BORE DIAM.	JIG BORE DEPTH	INT. GRIND	TAPER
A	—	1.991	THRU	1.999	1/2°INC
B	—	.493	THRU	.501	1/2°INC
C	5/32	.360	5/8	CLEAN	—
D	—	.304	THRU	.312	—

PUNCH PLATE

HOLE NO.	JIG BORE	C' BORE DIAM.	C' BORE DEPTH
A	.531	.593	.125
B	.531	.593	.125
C	.187	.250	.125

STRIPPER

HOLE NO.	JIG BORE
A	2.008
B	.508
C	.312
D	.312

Fig. 204 — Coordinate layout drawing for Jig Boring die in Fig. 31, preparatory to internal grinding. *Dowel holes also to be ground to maintain perpendicularity.*

around the Jig Borer. It is still employed, with a fair degree of success.

Although the Jig Borer is not suitable for correcting hole location by grinding, it can be used to *establish* location *preparatory* to grinding.

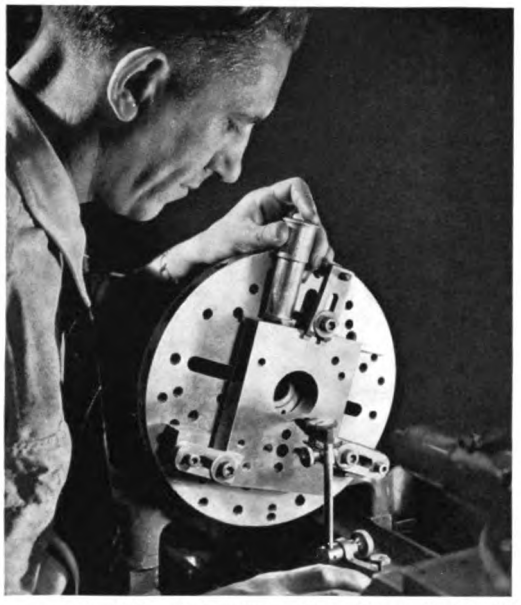
The die described in Fig. 31 provides an example. Let us assume the specifications now call for a die of high accuracy, to produce blanks from thin stock, Fig. 32.

The coordinate drawing, Fig. 204, is somewhat different from that in Fig. 157. Since thinner stock is used for the blank, the stock move is reduced from 2.078″ to 2.040″. Draft, or taper, is reduced from ½° to ¼° (see also Fig. 31).

After hardening, grind the top and bottom of die. First, indicate and grind the main blank hole, as in Fig. 205.

Brass plugs are next driven into the other holes, leaving a portion of the plugs extending above the surface of the die for indicating. Orientation of the die with respect to the main blank hole and the center piercing hole is accomplished in the Jig Borer by indicating, Fig. 206. Had it been necessary to favor the position of the main blank hole, a plug could have been inserted therein, also. In this case, however, it was deemed unnecessary, since plenty of stock for cleaning up was left in the other five holes.

Small holes are now drilled and bored into the brass plugs, Fig. 207. These holes are to be employed as reference points for grinding, and should be carefully bored



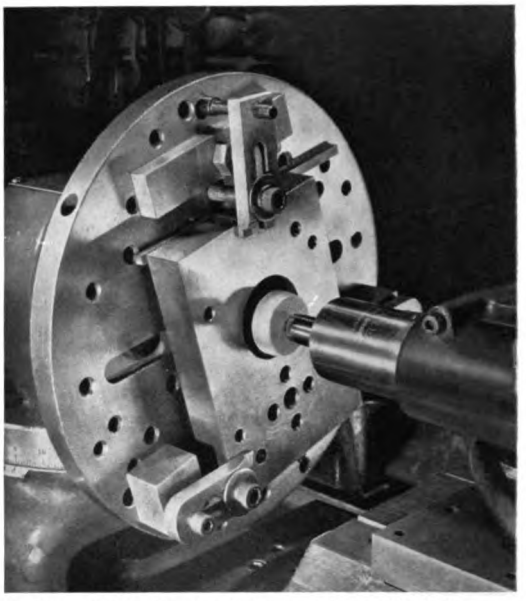
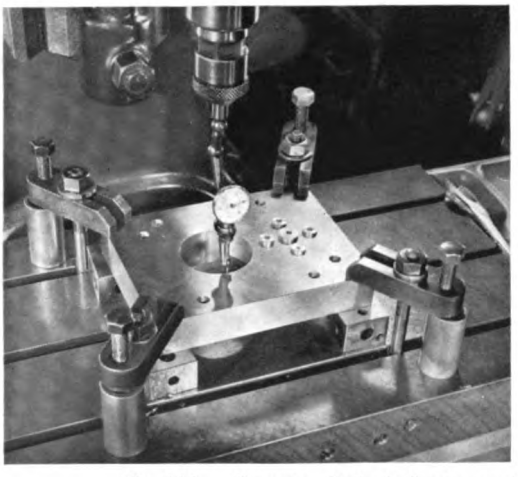


Fig. 205 — Indicating and grinding main blanking hole, from which all other holes may be established.



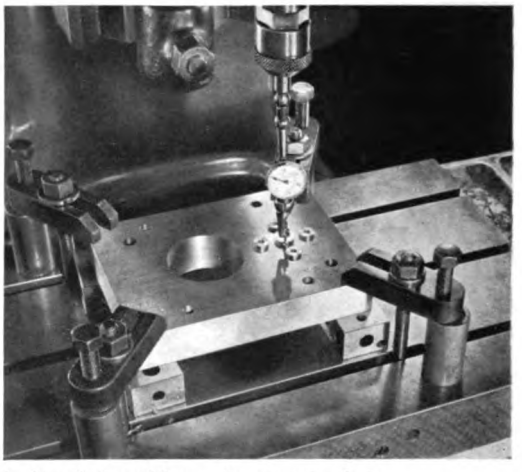


Fig. 206 — Orienting die by indicating main blanking hole and brass plugs in other holes.

to a good smooth finish. They need not be any particular size.

Each hole is now successively indicated on the internal grinder faceplate, Fig. 208, the plug withdrawn, and the hole in the die block finish-ground to location and size in the conventional manner, Fig. 209.

To facilitate withdrawal of the brass plug, the bottom end of the hole may be tapped. A screw inserted through a U-shaped block pulls the plug out easily, Fig. 210.

The results achieved by this procedure depend largely upon the skill and care employed. The condition of the grinder spindle (see also page 37) is an important factor. The chief difficulty is that of maintaining a close, but not too close, fit between the grinder spindle and its bearings.

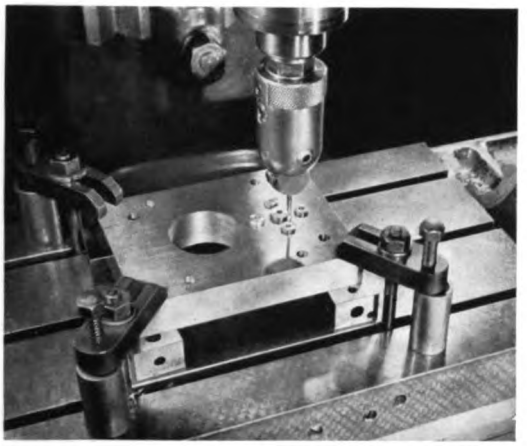


Fig. 207 — After die is oriented for position, small hole is bored in each brass plug.

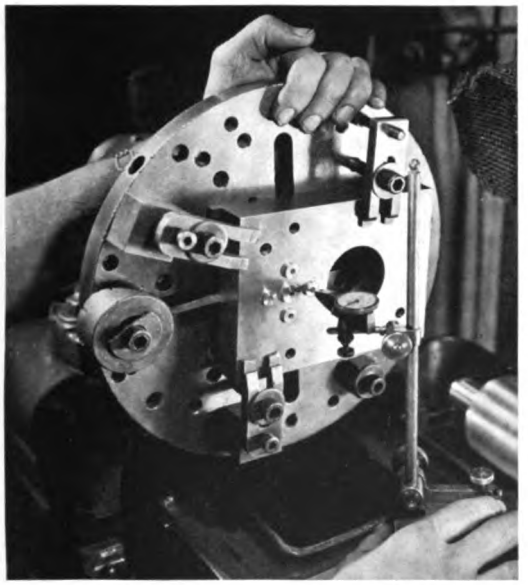
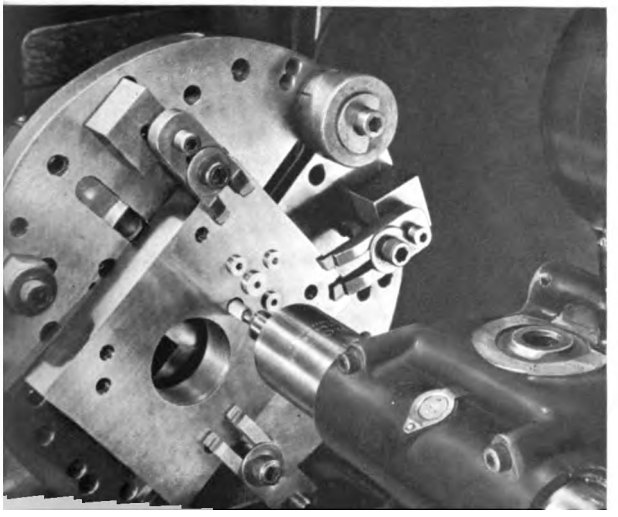


Fig. 208 — Each hole is now carefully indicated on faceplate of internal grinder or lathe.

Fig. 209 — After removal of brass plug, holes are ground in conventional manner.



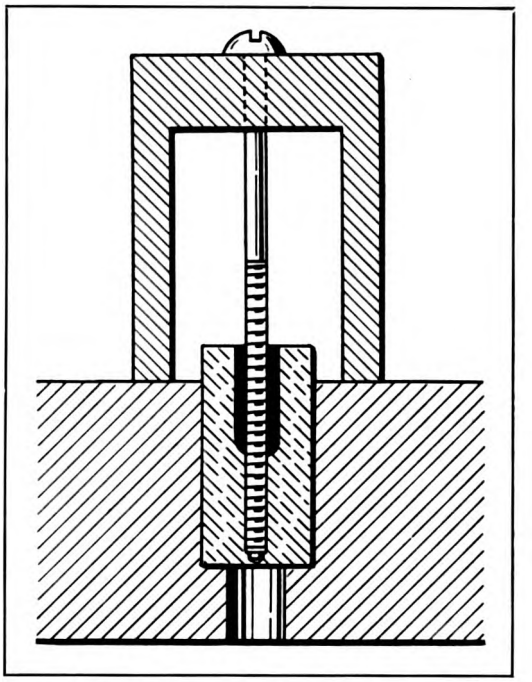


Fig. 210 — Brass plug is easily withdrawn by means of screw in hole tapped in brass plug.

After being ground, the die is again placed on the Jig Borer table, and each hole indicated to check its final position. Occasionally errors are found, due to the many steps required or the shifting of some part during the process. They can be corrected by indicating off-center on the faceplate by the same amount shown during the checking, and re-grinding, *provided* slight enlargement of the hole is permissible.

The stripper may either be bored after the grinding of the die, by doweling on top of the die, as in Fig. 167, or may be Jig Bored independently to the same coordinate layout. The punch plate is also Jig Bored independently to the same coordinate layout.

Locating the holes preparatory to grinding the above-described job is comparatively simple. Only one piece comprises the die block, and it is neither too large nor too heavy to swing on the faceplate.

The die in Fig. 211, however, is a different matter. Practically no errors are permissible, the best of skill must be employed, and the assembled die is much too large and heavy to swing on the faceplate. Among the complications are these:

1. High accuracy requirements in the finished blank:

Hole size +.0005″, −.0000″

Hole location ±.0005″.

2. Many holes in blank close together.

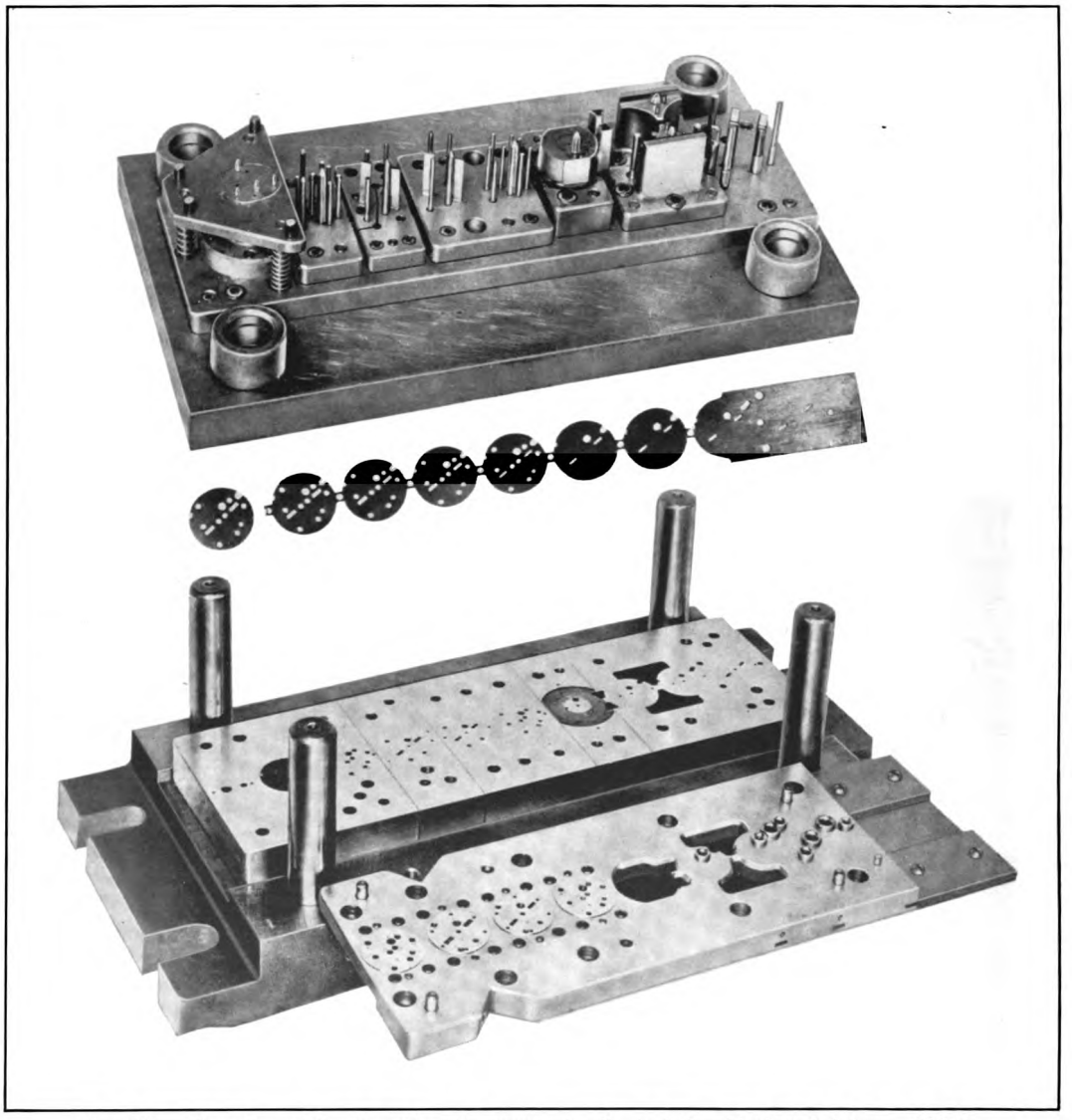


Fig. 211 — Complex multi-section, 10-station progressive die, including blank and skeleton. All holes are pierced and shaved, contour gutted and shaved.

This precludes the use of bushings.

3. High accuracy necessitates shaving of most holes, including rectangular slots. Control of stock move by pilots is, therefore, of prime importance. Not only must punches align accurately with die, but any pierced hole must also accurately align with its subsequent shaving station, to prevent cramping or chafing of punches.

4. Many stations in die — ten working stations in all. Stock feed from each station to the next must be sufficiently accurate to prevent any appreciable cumulative error over the ten moves.

5. Many sections in die — six in all. No error may be tolerated between stations in one section and other stations in other sections.

6. Hardened stripper inserts, to provide accurate guides for all piercing and shaving punches. Holes too close together in most cases to permit bushings.

A die with such requirements cannot tolerate the distortion and surface decarburization from heat-treatment. All holes must be ground.

Each section of the die is carefully Jig Bored and heat-treated. After aging, the edges of all the blocks are ground and fitted together and to the die shoe, being oriented with respect to the holes. All are doweled into the die shoe and brass plugs inserted into all holes. The entire assembled die is now strapped to the Jig Borer Table, and a small hole drilled and bored into each plug. The die is next disassembled, and each section swung up on the internal grinder faceplate, holes in the plugs indicated, plugs pushed out, and the die holes ground.

After grinding, the entire die is re-assembled to the die shoe and again put on the Jig Borer to check the positions of all holes. Due to the complication of the many steps in this procedure, there is a good chance that errors will creep in, and that some of the holes must be further corrected. At this point it is to be noted that corrections in a die with comparatively few bushed holes is a difficult matter, since correction is possible only by enlargement. Sometimes a whole section must be made over due to a small error in one hole. If the toolmaker feels that the risk of bringing these holes up to size is too great, he might decide to rough grind all the holes once, re-assemble the die, re-check, then disassemble and re-grind to compensate whatever errors he finds.

The above procedure marks the beginning of interchangeability in toolmaking, from a hole location standpoint, but leaves much to be desired. It is slow and tedious, and the many steps involved render the attainment of high accuracies extremely difficult.

More and more evident, therefore, is the necessity for an engineered solution to the problem of correcting holes in hardened work by grinding — a complete machine with built-in coordinate location system and grinding facilities.

Fig. 212 — Correcting holes to size and location in hardened die by Jig Grinding.

Chapter VI

HOLE GRINDING IN JIG TIME

THE MOORE JIG GRINDER resulted from the union of two major hole location principles—coordinate location and planetary grinding. This development was as inevitable as single-point boring by coordinate location, which resulted in the Jig Borer, Chapters III and IV. The Engineered Solution to the problem of correcting holes in hardened parts by grinding is a necessary partner to Jig Boring for a complete hole location service.

Location preparatory to grinding may be established by means of a Jig Borer, pages 152 to 157, but the subsequent process of disassembly, swinging and grinding on a lathe or internal grinder faceplate, reassembly and checking, is extremely laborious and tedious. Moreover, the multiplicity of necessary operations and the difficulty of maintaining good spindle conditions in the lathe or internal grinder render it prone to inaccuracies.

For best results, the disassembly process should be avoided. Location and grinding should be performed in a single setup, with all die sections mounted on their own dowels. However, if a heavy, complicated die, such as that in Fig. 211, should be swung up completely assembled on a faceplate, a huge machine would be required. This would necessitate extremely slow rotational speeds, and the grinding would be so slow as to destroy any economy in the practice. Use of this huge machine would also be detrimental to accuracy requirements.

Attempts have been made to convert Jig Borers for grinding by attaching planetary grinding spindles. Although they have proven helpful in some cases, they fall short because of the lack of certain essential in-built features, such as taper grinding, adjustability while running, and dirt exclusion.

Moore engineers, cognizant that no complete machine existed for grinding holes to location and that grinding is as essential to the hole locating problem as boring, set about its development. The result is the Moore Jig Grinder, the only machine of its kind, Fig. 213. The author takes leave to point out that just as Pratt & Whitney

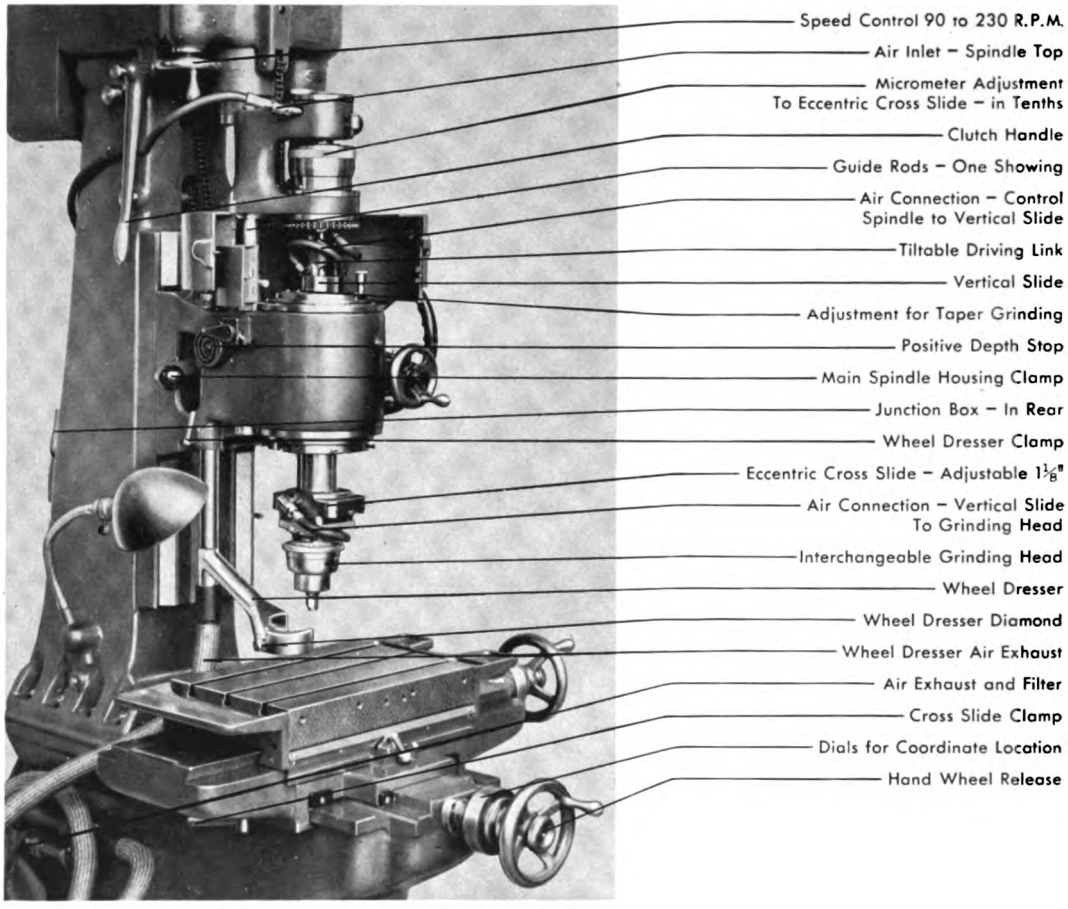


Fig. 213 — Design and control features of Moore Jig Grinder.

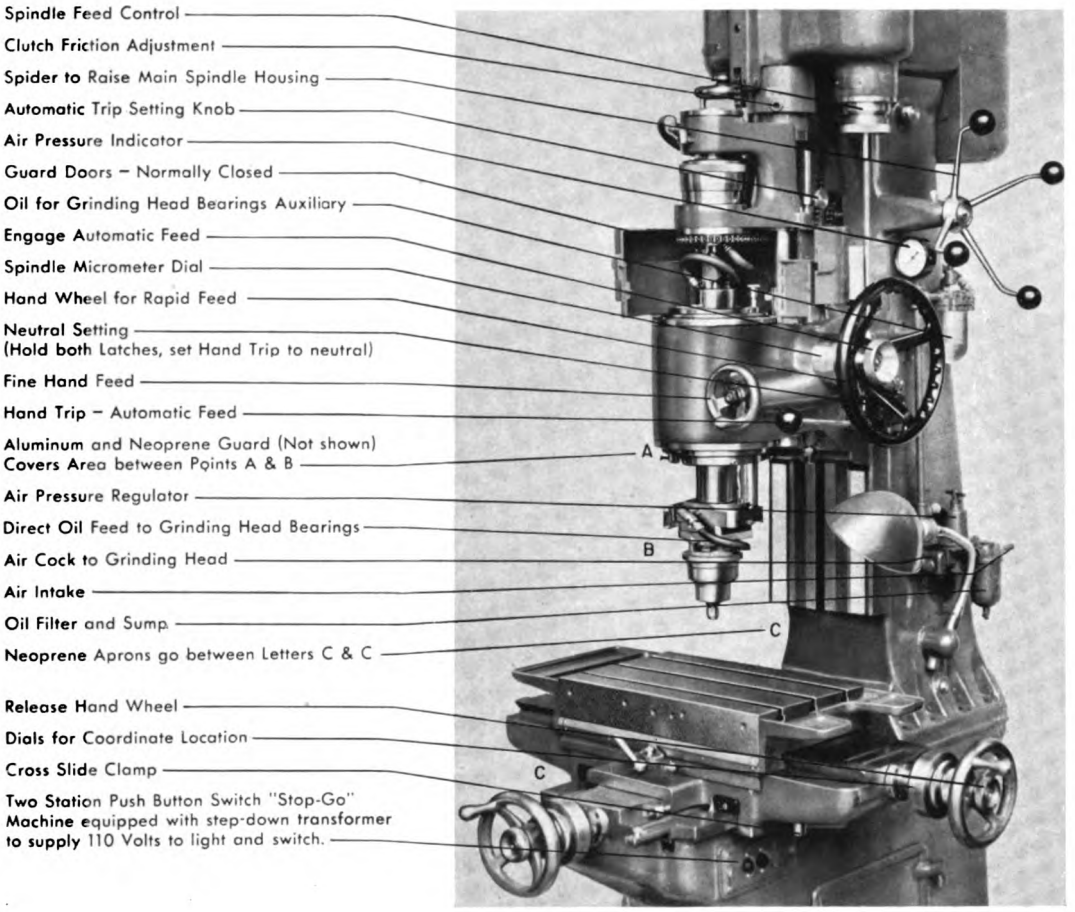
deserves full credit for developing and naming the Jig Borer, page 63, so the Moore Company rightly assumes credit for conceiving and giving name to the Jig Grinder.

Any hardened piece can be ground and inspected more accurately than a soft piece can be machined. Accuracy requirements of the Jig Grinder are therefore much more stringent than those of the Jig Borer. Among the reasons are the following:

1. The machine is always employed on finishing operations. While the Jig Borer is sometimes used for roughing, or boring preliminary to hardening, the job of the Jig Grinder is *always* the establishing of the final location.

2. Work is performed on hardened, highly-finished parts, insuring better checking conditions than in bored, soft pieces. Plugs can be fitted without introducing further inaccuracies due to loose fits or distortion, and errors unavoidable in soft, bored pieces are sure to be objectionable in hardened, highly-finished parts.

3. Effects from temperature changes


Spindle Feed Control
Clutch Friction Adjustment
Spider to Raise Main Spindle Housing
Automatic Trip Setting Knob
Air Pressure Indicator
Guard Doors – Normally Closed
Oil for Grinding Head Bearings Auxiliary
Engage Automatic Feed
Spindle Micrometer Dial
Hand Wheel for Rapid Feed
Neutral Setting
(Hold both Latches, set Hand Trip to neutral)
Fine Hand Feed
Hand Trip – Automatic Feed
Aluminum and Neoprene Guard (Not shown)
Covers Area between Points A & B
Air Pressure Regulator
Direct Oil Feed to Grinding Head Bearings
Air Cock to Grinding Head
Air Intake
Oil Filter and Sump
Neoprene Aprons go between Letters C & C
Release Hand Wheel
Dials for Coordinate Location
Cross Slide Clamp
Two Station Push Button Switch "Stop-Go"
Machine equipped with step-down transformer
to supply 110 Volts to light and switch.
A
B
C
C

Neoprene aprons and guards removed to show details.

are more troublesome. The grinding action is slower than boring, and a longer time is required for the completion of a piece of work. There is more time for temperature or other condition changes to occur.

4. Requirements in operator skill, especially when seeking the last "tenth". A good Jig Grinder operator must be a combination of Jig Borer and internal grinder operator. Such operators are extremely critical of anything which might detract from the certainty of attaining top results.

The difficulty of maintaining high accuracies is aggravated by the fact that more things are expected of a Jig Grinder. The design, therefore, is more complicated. The main spindle is augmented by a second spindle rotated eccentrically, in planetary fashion, to perform the grinding. This necessitates certain other features, not vital to Jig Borer operation but essential to grinding:

1. Offset adjustable while running. Attempts to perform Jig Grinding by attaching a grinding spindle to a Jig Borer have

shown the importance of being able to adjust the amount of eccentricity of the planetary grinding spindle while the machine is running. Since the purpose of the machine is to correct hole location, the hole to be ground is, at first, practically always eccentric from the main spindle, and one side of the hole starts to grind first. The actual spot is not known, and can be determined only under operating conditions. To be certain that the wheel will not hit too hard on the high spot, the machine must be started with a small enough eccentricity that it will not hit at all. If the machine did not have the adjustable-while-running feature, it would have to be repeatedly stopped, and the eccentricity advanced in small increments until the wheel made contact. Several minutes, instead of seconds, would be required to start grinding. The necessity of the adjustable-while-running feature can well be appreciated. Immediate wheel contact can be attained, and the wheel can be advanced to maintain efficient cutting action at all times without stopping the machine.

2. Taper grinding. Use of the Jig Grinder as a finishing machine for die-making necessitates grinding draft in the same setup as the grinding of all the other holes. Otherwise a separate setup of the die in a lathe or internal grinder would be necessary.

3. Wide speed variation of grinding spindles. Large holes and small holes, often ground in the same die, require a wide range of grinding wheel sizes and, therefore, a wide range of speeds. Since we have no single spindle which will run efficiently over wide speed ranges, several different heads, of various speeds, are available. New and more efficient grinding heads are constantly under experiment.

4. Protection from dirt. The exclusion of dirt from sliding ways and other moving parts is essential to all machine tools, *especially* grinding machines. Dust from grinding floats lightly in the air, settling on all exposed parts and creeping into the most obscure places, promoting rapid wear. None of the many types of protective guards entirely eliminates this, and most of them are difficult to remove for thorough cleaning. The neoprene aprons on the Moore Jig Grinder exclude most of the dirt from the slide ways and are easily lifted to facilitate cleaning.

In addition to the neoprene aprons, the Moore Jig Grinder is equipped with a venturi suction device, which may be connected to an air inductor placed under the workpiece, or the tubular arm holding the wheel-dressing diamond, Fig. 257. This draws off a large proportion of the dust immediately at its source. In addition, the free air-flow acts as a coolant, and reduces clogging and glazing of the wheel.

Protection of the main spindle internal assembly is achieved from an air pressure bias maintained by a small leak in one

of the air-hose connections, page 167. **Design and Constructional Details of Base, Cross Slide and Table** — The base, cross slide and table of the Jig Grinder are practically identical with those of the Jig Borer. The same type of close-grained, nickel-bearing semi-steel castings are employed, finished with the same high-precision workmanship.

The lead screw measuring principle is also the same, permitting full use of the coordinate location system. This is fully as important in the Jig Grinder as in the Jig Borer to encourage the operator to rough-grind all holes before finish-grinding. See also pages 203 and 204.

General Construction of Main Spindle and Housing — The general construction of the main spindle is shown in Fig. 214. The axis of rotation of the main spindle determines the center of any hole ground. A true axis of rotation is established by a pair of heavily pre-loaded super-precision ball bearings, mounted in the spindle

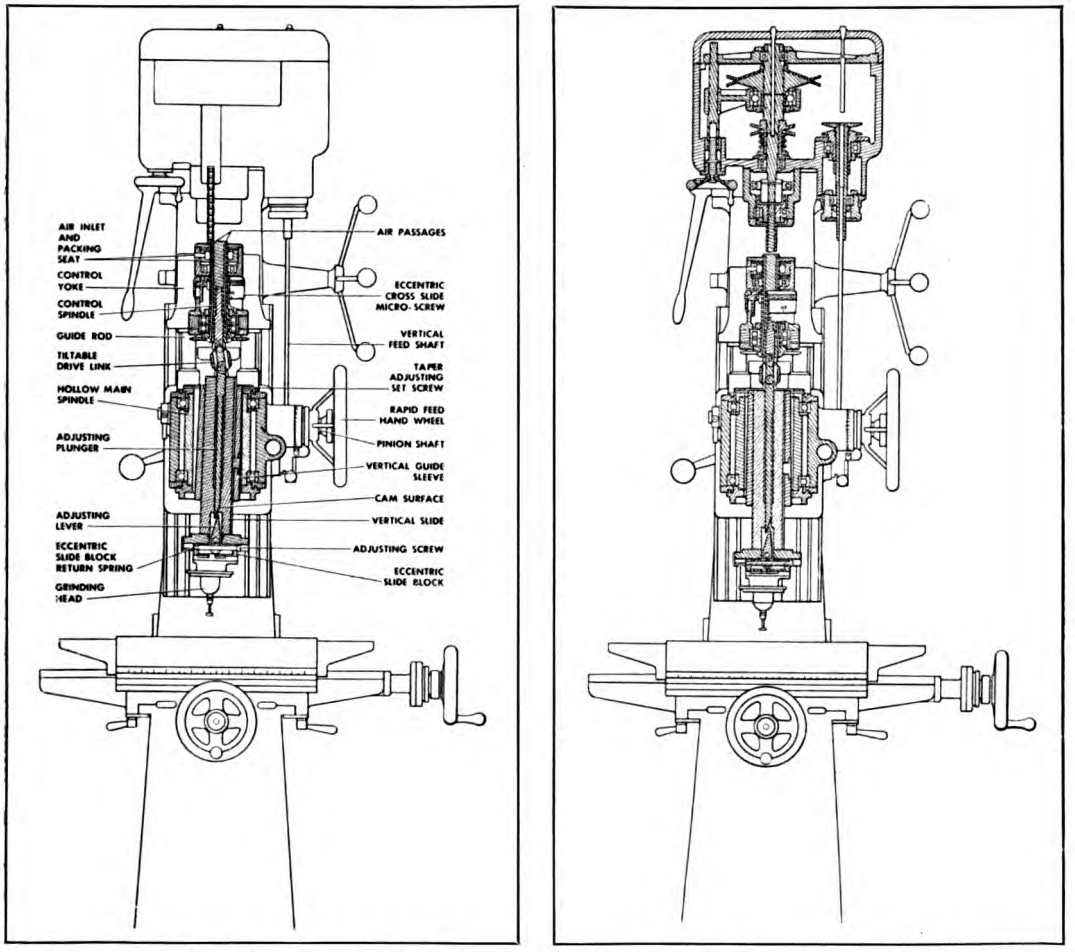


Fig. 214 — Design details of Moore Jig Grinder main spindle — left, set for taper grinding; right, for cylindrical grinding.

housing and carrying the hollow main spindle. Inside the hollow spindle is a guide sleeve, which, in turn, guides the vertical slide in its up-and-down motion in traversing the work. The grinding head is mounted on the bottom end of the vertical slide, its axis parallel to the direction of travel.

To minimize the effect of thermal expansion, the main spindle housing is cast from a low-expansion invar cast iron mixture containing 36% nickel, the same as in the Jig Borer.

Control Yoke and Control Spindle — To avoid any disturbance of main spindle alignment from chain pull or other driving effect, it is driven through a link by an independently-driven control spindle, mounted in the control yoke. The control yoke is mounted upon a pair of guide rods, moved up and down by pinions and racks by means of the rapid-travel handwheel. Up-and-down movement of the control yoke together with rotation of the control spindle imparts the proper combination of rotary and up-and-down motions to the vertical slide. The drive link provides a universal joint effect, minimizing undesirable lateral thrusts.

Taper Feature and Taper Setting — To permit the grinding of tapered holes, the guide sleeve may be tilted on an angle, guiding the vertical slide in an angular direction. The combination of rotation and angular traverse generates a true cone, the path of which determines the taper ground in the hole. The axis of rotation of the grinding wheel is always parallel to the side of the hole being ground; the grinding wheel, therefore, is always dressed to a cylindrical shape, Fig. 215. The guide sleeve is tilted about closely-fitted pivot pins at the bottom end. The angle through which the guide sleeve is tilted may be read on a scale at the upper end. Setting is achieved by means of two socket set screws, mounted opposite each other, Fig. 267. When settings are made, do not tighten these screws too tightly; avoid straining the hollow spindle and making it assume an out-of-round shape.

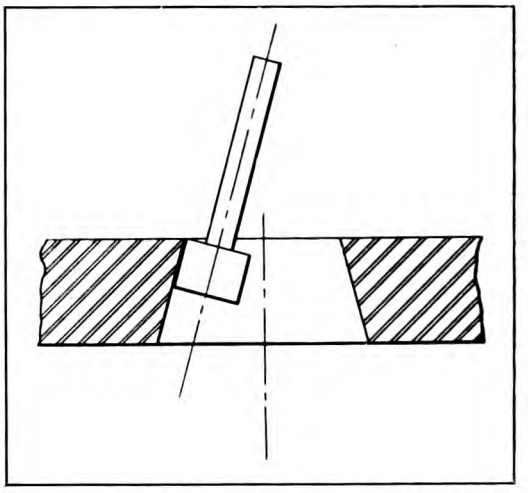


Fig. 215 — Even when grinding tapered holes, wheel is dressed to true cylinder, its axis and travel parallel to tapered side of hole.

The necessity for the type of driving mechanism employed is now apparent. The driving link is tiltable with respect to the control spindle and the vertical slide, yet its driving action is performed without influencing the position of the main axis of rotation.

Eccentric Adjustment and Eccentric Feeding — Attachment of Grinding Heads — The grinding head is not mounted directly on the end of the vertical slide, but is attached to a block which slides in dovetail ways. The head is centrally located by a boss on the slide block and held by four screws. The screw holes are pear-shaped, permitting removal of the grinding head without removal of the screws, by rotating the whole head a small part of a turn after loosening the screws. Attachment is achieved by reversing the process. The air hose is attached with a bayonet-type coupler.

The amount of eccentricity may be adjusted by either of two controls — roughly by means of the adjusting screw, which can be reached through the oval slot in the aluminum guard while the machine is stopped, or in fine increments by means of the control knob *while the machine is running*. The provisions made for these adjustments are evident in Fig. 214. The adjusting screw, holding the slide block against the pressure of the springs, runs through a nut in the adjusting lever. Either turning of the screw or movement of the nut causes the slide block to move.

Grinding is intended to be done on the side of the wheel *opposite* the oval slot, Fig. 216, since, in this direction, the movement of the eccentric slide block is positive, whether by turning the screw or the control knob, Fig. 214.

Rough adjustment is achieved by turning the screw in the nut. Fine adjustment is accomplished by moving the lever holding the nut. The series of parts through which it is done extends up through the center of the entire mechanism. Movement originates with the control knob. The screw threads inside the control knob cause it to move up or down as it is rotated. This pushes against the thrust bearing, the inner race of which, in turn, thrusts against a pin through the plunger. Movement is then carried through the angular adjusting link down to the cam, the tapered surface on the end of which moves the lever. The control knob is graduated in "tenths". The heavy spring load removes all backlash, and the movement is extremely sensitive.

When making settings, it should always be remembered that each "tenth" of adjustment represents a movement of one "tenth" on the eccentric slide; this removes two "tenths" of material from the *diameter* of the hole.

Fig. 216 — Always grind on side of wheel opposite oval rough adjustment slot.

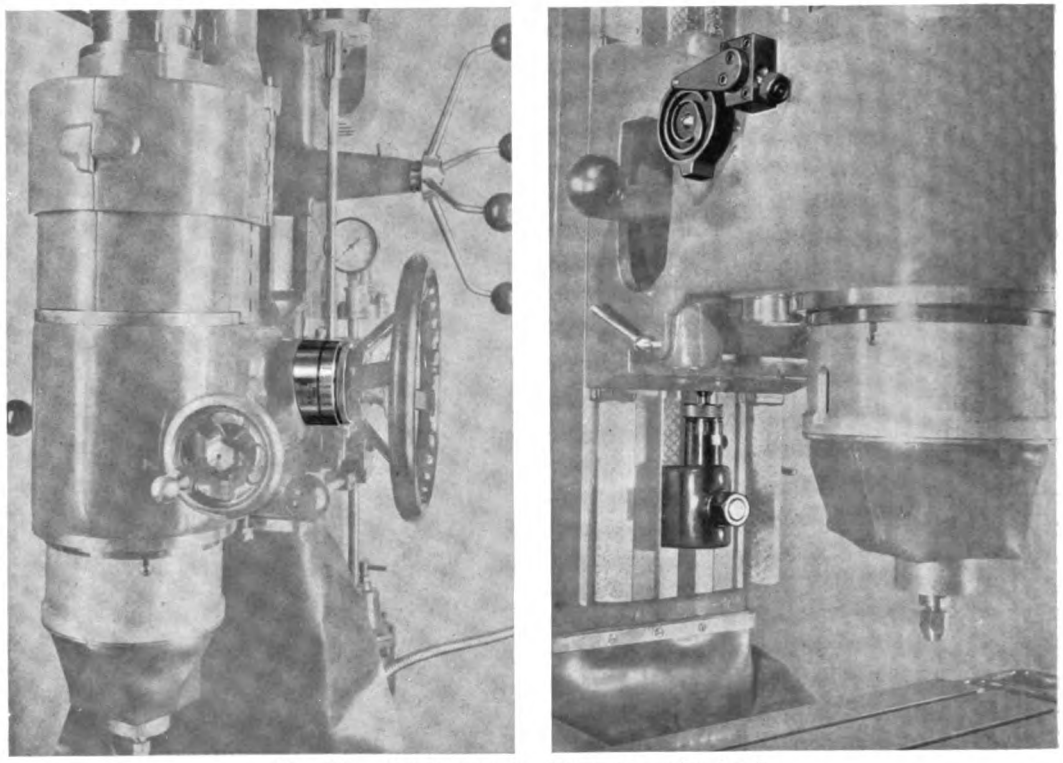


Fig. 217 — Depth measuring devices, Moore Jig Grinder.

The rough adjustment moves on a 40-pitch screw. No graduations are present; adjustment is made by the operator's estimate. Wherever the rough adjustment leaves off, the fine adjustment picks up and carries on immediately.

Depth Measuring Features — The Moore Jig Grinder, like the Moore Jig Borer, has three distinct devices for measuring and controlling the depths of holes, Fig. 217.

1. Adjustable positive stop on pinion shaft, with micro adjustment.

2. Graduated dial and vernier on pinion shaft, reading to .001″.

3. Micrometer Stop on column (supplied as an accessory).

The adjustable positive stop is on the left end of the pinion shaft. This type of stop enables the operator to use the full travel without the usual interference, since a pin in the spiral groove of the stop itself swings the limiting screw clear on the up-stroke. Micro adjustment is attained by turning the limiting screw.

The graduated dial, Fig. 217 (left), shows the travel of the quill. This dial, which can be set to zero at any position of the quill, is graduated in hundredths and reads, by means of a vernier, in thousandths.

Dirt Exclusion From Main Spindle Assembly by Pressure Bias — All working

parts of the main spindle assembly are made from hardened steel, ground and lapped. The exclusion of dirt from this complex assembly is of vital importance to its operation. Although surrounded by guards, it is not really sealed, and dirt floating in the air could get in except for the fact that a slight leak is left in the air line. A tiny hole is drilled into the Y-shaped air fitting in the top of the vertical slide, permitting air to escape at all times while the machine is running. This air maintains a slight outward pressure at all the unsealed joints, preventing the outside dirt-carrying air from getting in.

Diamond Dressing Arm — The built-in wheel dresser consists of a tubular arm mounting an adjustable diamond, Fig. 257. Rough adjustment is made by swinging the arm to approximately the correct position. Final approach to the wheel is achieved by gradually screwing the diamond in through the arm. The vacuum hose may be attached to the arm for removal of dust created during dressing.

This dressing arm is not completely universal, and sometimes interferes with projections on the workpiece. For the hard-to-get-at places, another type of diamond dresser is furnished, Fig. 258. This consists of a small block, holding a diamond, presented to the wheel by hand.

Main Spindle Drive — The main spindle is driven, through a tiltable drive link, by the control spindle in the yoke. This, in turn, is driven by means of a large sprocket, a chain, and another smaller ball-bearing-mounted sprocket in the rear of the yoke. Power is supplied to this second sprocket by a splined shaft extending downward from the drive housing. The splined shaft permits vertical travel of the yoke and vertical slide.

The drive housing contains the motor and a pair of Reeves variable speed pulleys, the driven pulley on a separate shaft directly over and connected to the splined shaft through a clutch. By means of this clutch, the motor and pulleys can be isolated from the splined shaft, permitting easy rotation, by hand, of the main spindle for purposes of indicating and setting-up. Rotational speed of the main spindle is controlled by the handwheel on the left-hand front bottom side of the drive housing.

Vertical Feeding—Automatic and Hand — A second pair of Reeves-type variable speed pulleys transmits power to the power feed shaft, protruding from the bottom front right-hand side of the drive housing. Speed control is achieved by turning the power feed control knob. The power feed shaft, like the main drive shaft, is splined to permit up-and-down movement of the main spindle housing.

The splined shaft drives right and left-hand worms, meshing with worm wheels. Toothed clutches engage, optionally, either of these to the horizontal fine hand feed shaft. A worm on this shaft drives a worm wheel on the rapid hand feed shaft, caus-

ing up or down movement of the control yoke through pinions and racks, as explained on page 164. The direction of travel depends upon whether the right or left-hand worm wheel is engaged.

The machine is arranged for automatic reversing of the power traverse. With the tripping nuts and the tripping knob set to the proper positions, vertical travel causes the tripping rod to build up spring pressure against the plunger in the clutch housing. Further travel trips a trigger, and the spring pressure throws the plunger and the clutch to engage the opposite worm. The tripping may also be accomplished manually, by throwing the black-knobbed reversing lever up or down.

Hand feeding is accomplished by the rapid hand feed handwheel, or the fine feed handwheel. To use the rapid feed handwheel, merely disengage by loosening the friction clutch inside the handwheel. To use the fine feed handwheel, the clutches in the clutch housing must be set at neutral by holding both triggers, or latches, so neither end of the plunger can engage, and setting the black-knobbed lever to neutral. The knurled knob inside the rapid handwheel should now be tightened. Rotation of the fine feed handwheel now causes up or down movement of the yoke and vertical slide. The fine hand feed is usually employed for "plunge" grinding, Fig. 234.

Extension of Hole Location Service — The Moore Jig Grinder is an extension of the idea of complete hole location service. As with the Jig Borer, the machine alone is not sufficient. The service also embraces convenience of operation, operator "know-how", and a full complement of small tools necessary to the three basic hole locating steps — locating, grinding, and inspecting.

Accessories and Small Tools — Moore Jig Grinder accessories are given the same thorough consideration as those employed with the Moore Jig Borer. Less tooling is generally required for the Jig Grinder, because it is used for fewer types of operation. While the Jig Borer is used for spotting, drilling, boring, reaming and inspecting, the Jig Grinder is used only for grinding and inspecting. Fewer tool changes are, therefore, required. For this reason, the Jig Grinder has been aptly called the "lazy man's machine". The term is somewhat misleading, because of the greater refinements in work performed.

The following pages show accessories developed for the Jig Grinder. Although it is evident from their purpose that some of these are the same as used with the Jig Borer, they are repeated here because their applications are sometimes slightly different. Examples at this point will acquaint the reader and help him in understanding future instructions.

Storage Cabinets — The large desk-type cabinet, or the small cabinet, Fig. 218, should be placed close enough to the machine to enable the operator to reach any

Fig. 218 — A similar choice of cabinets to that for Jig Borer is available for Jig Grinder.

tool without leaving his workplace. The large cabinet provides a storage place for all necessary accessories, including bolts and straps, rotary table, angle-plate, grinding heads, workpieces, or other parts which may accumulate. All drawers and doors may be closed by a single lock and key. It is equipped with the same blueprint rack as is provided for the Jig Borer cabinet.

The small cabinet obviously cannot be so complete as the large one. Intended for use where a bench is already available, it is suitable for holding bolts and straps, pickup devices, and other small tools.

Work-Holding Devices — As in the Jig Borer, the most commonly used work-holding tools for the Jig Grinder are bolts and straps, Fig. 219. Parallel setup blocks are fully as useful in the Jig Grinder as in the Borer. The precision vise is also a valuable work-holding device for the Jig Grinder, especially for small-lot production work, such as machine parts, Fig. 220.

When grinding with diamond-charged mandrels, pages 181 to 189, no sparks are emitted. It is difficult to determine, therefore, the exact moment of contact with the work. To facilitate this, an electronic amplifier, Fig. 221, is connected to the work, making an audible sound when contact is made. This necessitates electrically insulating the workpiece from the machine table. For this purpose, insulated parallels

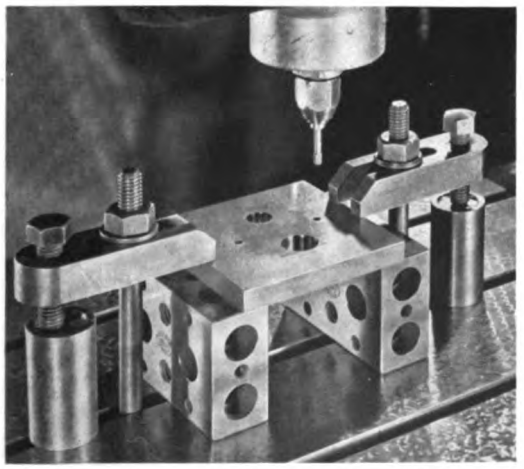


Fig. 219 — Universal work-holding devices — bolts and straps. Also, parallel setup blocks.

Fig. 220 — Small-lot production Jig Grinding with precision vise.

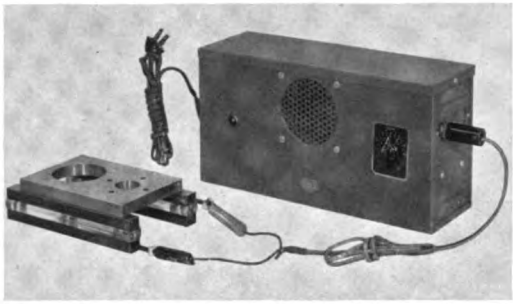


Fig. 221 — Electronic amplifier and insulated work-supporting parallels.

are available. When setting up work on these, care must be exercised that the work is not short-circuited by the bolts and straps. A piece of paper under the toes of the straps prevents this.

Air-Driven Grinding Heads — The large variety of hole sizes to be ground in the Jig Grinder necessitates the use of both large and small grinding wheels. This, in turn, necessitates a wide range of grinding spindle speeds.

To perform the work most efficiently, the necessary wide range of speeds should be incorporated into one grinding head to eliminate changes between different-sized holes on the same job. Experiments are currently being conducted to test the feasibility of this, with a certain degree of success, in that variations in speed of the same head may cover part of the range.

It does not yet appear possible to cover the *entire* range with the same head, however. Therefore, two different heads are at present available, Fig. 222; a turbine-type operating at approximately 50,000 RPM, and a vane-type, operating at approximately 14,000 RPM.

The method of attaching is illustrated in Fig. 223. The mounting flange is fitted over a centralizing boss on the bottom of the eccentric slide block. Screws, left permanently in the slide block, slip through the large ends of pear-shaped holes in the mounting flange. Rotation of the head on the slide block aligns the screws simultaneously with the small ends of the pear-shaped holes. The head is made fast by tightening the screws. The air line is attached by means of a simple bayonet lock. Next, the aluminum attachment guard is slipped over the bottom end of the main spindle and the Phillips head screws tightened. The nose of the grinding spindle and enough of the body for attachment of the indicator are now exposed; the operating parts are entirely enclosed and protected from dirt by the aluminum attachment guard and the rawhide boot.

The question why air, instead of electricity, is used to drive the grinding spindles is frequently raised. Considerable progress has been made in the development of high-frequency, high-speed electric motors for internal grinding. As yet, how-

Fig. 222 — 14,000 and 50,000 RPM grinding heads.

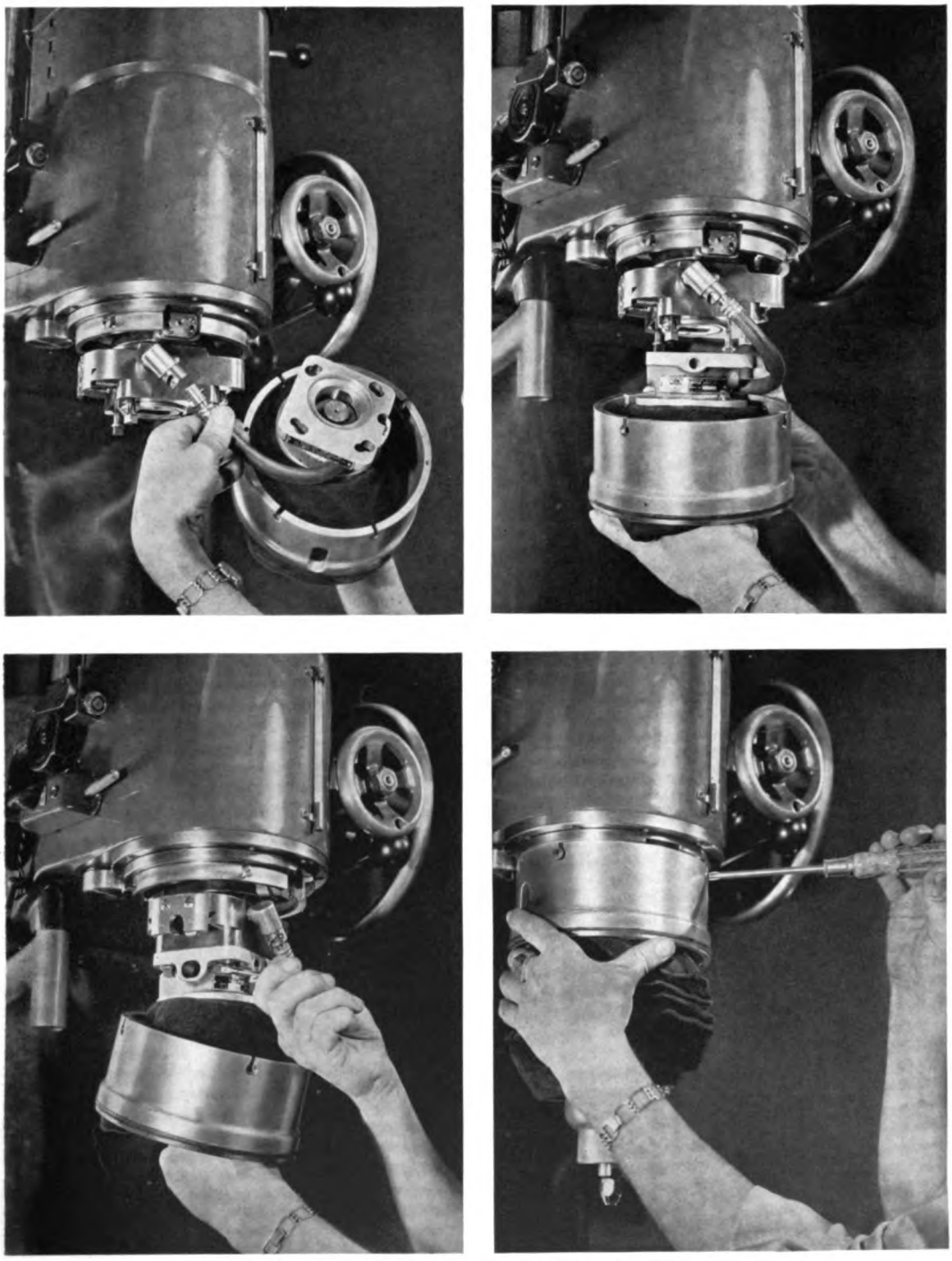


Fig. 223 — Attaching grinding head to main spindle.

ever, it does not appear advisable to adopt these to the Jig Grinder. Among the reasons are:

1. Electric motors are necessarily more complex and expensive than air-driven motors. Parts are larger and heavier, more difficult to squeeze into restricted spaces and more difficult to balance.

2. High-frequency motors for high speeds require expensive motor-generators for supplying power. Air-driven heads, likewise, require compressed air, but most shops are already equipped with compressors, while few are equipped with high-frequency generators. Their use is uncommon, and each generator is usually built especially for each application.

3. Electric motors require a supply of air to cool the windings, especially high-frequency motors, which draw large amounts of power in proportion to their size. In the Jig Grinder, this would require provisions for leading *both* air and three-phase electric current to the point of use. This would further complicate an already complex device. Since a considerable volume of air is required for cooling, it may as well be used for driving the motor in the first place.

4. Air employed to cool the electric motor will be non-uniformly warmed in the process, the degree depending upon the length of time the motor has run, power drawn, variations in power factor, and other variations beyond control. Exhaust air from air motors, by contrast, is uniformly cool, and may be used to control the temperature of the workpiece by flowing directly upon it. See pages 174 and 175.

5. Experiments currently under way indicate that controllable speed variations may be achieved over fully as wide a range as with electricity.

Locating, Inspection, Measuring Tools — The indicator set used for the Jig Grinder, Fig. 224, is similar to that used for the Jig Borer, except that the wiggler, or line finder, is omitted. It consists of an indicator with holder and an edge finder. A clamp ring, to hold the jointed indicator holder to the grinding head, is furnished with each machine.

Fig. 224 — Special clamp ring for attaching indicator holder to Jig Grinder spindle.

In general, the same types of devices for measuring hole *sizes* are employed in the Jig Grinder as in the Jig Borer, pages 113 to 117. In this connection, it is far more difficult to control bellmouth in *ground* holes than in *bored* holes, for two reasons:

1. A boring tool being relatively stiffer, and touching only one point, bores very nearly the same size all the way down. A grinding wheel, or diamond mandrel, on the other hand, requires some pressure for grinding. This pressure always bends the mandrel slightly, reducing the hole size when the entire wheel is in contact. At the ends of the hole, when only a small portion of the grinding wheel is in contact, unit pressures are increased, and the hole is ground larger.

2. Grinding is usually thought of in terms of "tenths" instead of "thousandths", and an *equal* amount of bellmouth is *relatively* larger and, therefore, more objectionable.

For these reasons, measuring holes with slow taper plug gages or the leaf taper gages should be done carefully. They might hit some high spot in the hole instead of the end. Nothing beats a straight plug gage for finding and eliminating this. On high-precision work, availability of a plug gage for final sizing is a vital necessity.

The plug gage does not readily expose deviations from roundness or irregularities in size, such as taper. The internal indicator, Fig. 225, although somewhat expensive, is very effective. It may be inserted in any direction or to any depth, and reads the size across any diameter. Small errors in taper, bellmouth, or out-of-roundness are readily discernible. The internal indicator may be set against a standard ring gage, or with the micrometer.

A more recently-developed tool is an internal gage whose principle of operation is based on back-pressure of escaping air from jets in close proximity to the sides of the hole. These are understood to be extremely sensitive but not readily adjustable. Their use is, therefore, largely restricted to high-production work.

Angular Spacing Devices — The same three basic angular measuring devices employed with the Jig Borer are also

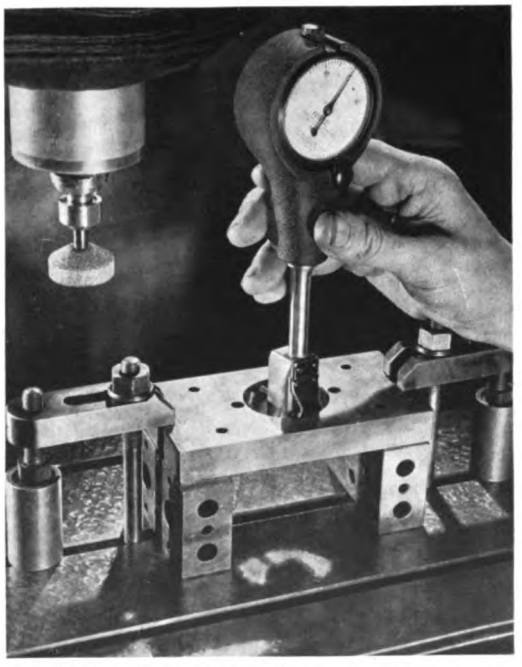


Fig. 225 — The internal indicator provides extremely sensitive internal measurements.

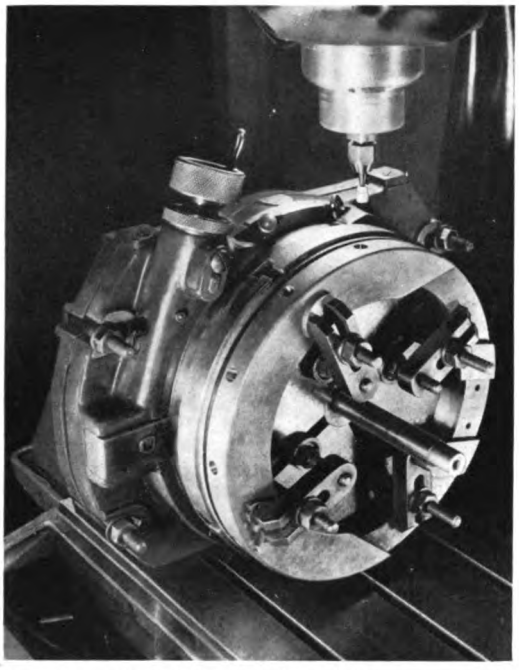


Fig. 226 — Jig Grinding of holes radially or tangentially may be performed with rotary table and right angle plate combined.

suitable for the Jig Grinder, namely, the rotary table, the right angle plate, Fig. 226, and the micro-sine plate, Fig. 275. To attain the essential spindle height for radial grinding on large diameters as in Fig. 226, the riser block must be employed, Fig. 227.

Depth Measuring and Micrometer Stop — Fig. 217 shows the same micrometer stop as is used in the Jig Borer, installed on the Jig Grinder. It is used for the same purpose, in connection with the two other depth-measuring features, to prevent loss of dial and positive stop settings when raising or lowering the main spindle housing.

Riser Block, Sub-Table, and Extension Plate — The riser block, Fig. 227, is usually more in demand for use in the Jig Grinder than in the Borer, due to the length of the grinding heads. The extension plate is seldom employed in the Jig Grinder, since, with present design, it is necessary to remove the visor and neoprene aprons.

The sub-table, Fig. 228, serves the same purpose, that of restoring the original height relationship from table to spindle when the riser block is in place.

Temperature Considerations—Thermostatic Heating Unit — Although the use of invar iron in the main spindle housing reduces considerably the effect of temperature changes, it does not take care of all thermal expansion effects. For the ultimate precision of which this machine is capable, we strongly recommend that it

Fig. 227 — As in Jig Borer, riser block and extension plate extend size range of Jig Grinder.

Fig. 228 — Sub-table restores original spindle-table relationship when riser block is employed.

be kept in a constant-temperature room, and that the compressed air for the grinding heads be supplied at approximately 2° above room temperature. If cooling has been employed to condense out the moisture, it should be re-warmed.

Constant temperature prevents the base, cross-slide, table and lead screws from temperature changes and, with them, the normal expansion and contraction of the materials of which they are composed.

The reason for holding the compressed air at constant temperature 2° above room temperature is that the exhaust air from the grinding heads is designed to flow over the work, keeping it cool. Inasmuch as air cools upon expansion, the air should be delivered to the machine slightly warmer than the room. Upon expansion, it will cool to, or a little below, room temperature. In cases where the air temperature is subject to too great fluctuations, it is advisable to install thermostatically controlled temperature-correcting devices.

In addition to the above precautions, it is sometimes advisable to install a thermostatically-controlled heater in the main spindle housing, Fig. 229. This should be set to the highest temperature the housing would attain if permitted to run indefinitely. Experiments are constantly under way to improve the efficacy of this.

A thermometer mounted on the front of the main spindle housing is also helpful in assuring the operator that no appreciable changes occur. A high degree of precision is attainable without some of the refinements in consideration of temperature effects above mentioned. Since the resultant error in any position is the total of many small errors, the ultimate is attained only through the elimination of *every* error, however small. To achieve best results, all should be considered.

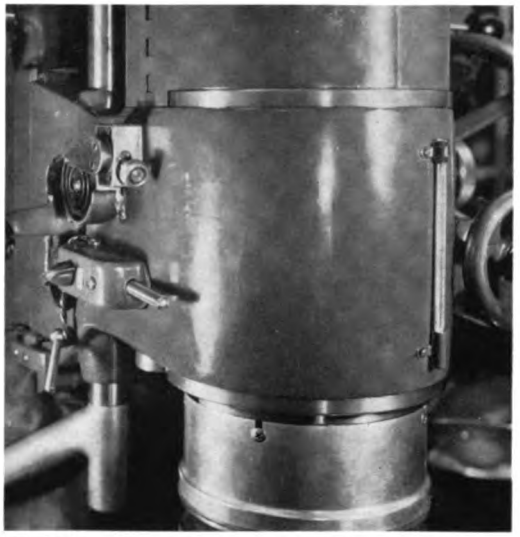


Fig. 229 — For ultimate precision constant temperature of spindle housing must be maintained. Note thermostat and thermometers.

Grinding Wheels and Diamond Dust — Abrasive materials, such as grinding wheels, mounted points, and diamond dust for charging mandrels, are as essential to the Jig Grinder as boring bits to the Jig Borer. For this reason, any company building a grinding machine should be prepared to experiment and consult with its users enough to give them good advice on the selection of these materials.

The Moore Company is especially fortunate in this respect. Operating a full-scale

contract tool room, it keeps three to four Jig Grinders in constant use, and is able to acquire considerable experience in the selection and stocking of proper abrasive supplies. See also *Grinding Wheel Selection*, pages 189 to 191, and *Grinding with Diamond-Charged Mandrels*, pages 181 to 189.

The Coordinate Location System — The same system for Coordinate Location is employed with the Jig Grinder as with the Borer, and has, in general, the same advantages. Holes on a certain piece of work may be rough-ground before finish-grinding, to insure the best uniformity of conditions. If the Moore Jig Borer and Jig Grinder are used, the same coordinate layout made for the Borer is also suitable for the Grinder when holes are subsequently to be ground.

Operational Practices, General — Before proceeding to examples of operational practices, the reader should be acquainted with some of the general principles and definitions. Jig Grinding, like Jig Boring, may be resolved into three fundamental steps:

1. Location (setting up, picking up starting point, determining location of each hole).

2. Cutting, or grinding.

3. Inspection.

The preferred procedure, after setting up, is to rough-grind all holes, then go back and make a fresh pickup, in case vibration or thermal changes have altered it, before finish-grinding. Frequently, this procedure is of assistance in bringing holes to size, especially if several holes in the same workpiece are to be the same size. Holes rough-ground to a uniform, nearly-finished size may be brought to size one after another with little or no change in the eccentric adjustment.

Setting Up the Work — Work-holding devices should always be used with care, to avoid distortion of the workpiece or table. These points should be remembered:

1. When using bolts and straps, keep the bolts as close to the workpiece as possible.

2. Place the straps exactly over the points of contact with the parallels. Placing a strap over a part of the workpiece not supported by a parallel is sure to distort it. Parallel setup blocks were devised to minimize this danger. Spacing four or six of these around a workpiece, Fig. 107, gives better support, in many cases, than a single pair of parallels.

3. Do not tighten bolts more than necessary to prevent the workpiece from shifting its position.

4. When using the vise, Fig. 220, do not clamp the workpiece too tightly. It is possible to spring the stationary jaw, and, with it, dislocate the working edge of the workpiece.

Use parallels of sufficient height to permit grinding wheels to go through without

hitting the table. Additional height is often required for measuring the bottoms of holes ground, Fig. 270.

Wherever feasible, make provision for inserting one of the air inductors under the workpiece, Figs. 257 and 258, to draw off the grinding dust, keeping it out of the machine ways.

The workpiece is usually oriented parallel to the table travel by one of three methods, also applicable to the Jig Borer:

1. Indicate one or both sides of the workpiece.

2. Indicate two or more holes in the workpiece, orienting the work to suit the average location of a group of holes previously bored but distorted by heat treatment.

3. Push one edge of the workpiece against the straight edge at the back of the table. It often is not advisable to place the work *directly* against the straight edge, but space it away with feelers or parallels. This brings the work into a more favorable working position near the center of travel, and helps to ascertain whether the work, after being clamped down, is in contact at both ends.

The indicator is preferred as the most dependable, especially in cases requiring high accuracies.

The rotary table, because it is easily turned through small angles and clamped, is a convenient device for orienting workpieces angularly, even at times when rectangular coordinates are employed, Figs. 230 to 233.

Making Table Settings — The micrometer lead screws in the Moore Jig Grinder, as in the Moore Jig Borer, provide the measuring system. When making settings, always turn the handwheels in a clockwise direction, as indicated by the arrow on the zero dial. When it is necessary to go backwards, go past the setting a little more than the backlash, *then always turn clockwise for making the final setting.*

Locating Position of Workpiece in the Coordinate Location System with Respect to the Spindle — Indicators and other devices for "picking up" edges, holes, or bosses on the workpiece with respect to the axis of the main spindle have been previously shown. After the spindle has been centralized with the desired reference point on the work, the scales and dials may be loosened and set to their proper readings, corresponding with the coordinates established for that particular reference point. *The dials are not necessarily set at zero.* Sometimes the location of the reference point has already been determined by Jig Boring. When this point is picked up in the Jig Grinder, the dials and scales should be set to the original coordinates shown on the same sketch as was used in the boring. In case of severe distortion from heat treatment, it often happens that one hole, or edge, alone is not a sufficient reference point. Often two or three

Fig. 230 — Picking up rotary table center.

Fig. 231 — Picking up center hole of workpiece.

Fig. 232 — Picking up other holes, orient workpiece with rotary table to average errors of all holes.

Fig. 233 — Application similar to Figs. 230 to 232, except on larger workpiece.

holes are picked up, and the final setting is a compromise among the errors found.

The rotary table is sometimes used purely for angular orientation of the workpiece in the machine, Figs. 230 to 233, even though it may not be used actually to determine angular spacing. An example of this is in picking up a previously bored or ground part, wherein no edge is available and no two holes are on the same coordinate line. Angular orientation and coordinate positions are both

required, the former provided by rotation of the rotary table and the latter by table settings.

Pick up the center of the rotary table, Fig. 230. Lightly strap workpiece on rotary table, Fig. 231, and tap it around until starting hole is true both with spindle and center of rotary table. Set scales and dials to coordinates for this hole (coordinates previously established for Jig Boring, or new coordinate location sketch). Move table to coordinates of some other hole, to be used for alignment. Rotate table until this hole can be picked up and indicated true with spindle, Fig. 232. Since the starting hole has been previously set true with the center of the rotary table, its position has not changed, but should be re-checked. To attain a true average position among all the holes, coordinate settings should be made to several of them. Final scale, dial, and rotary table settings are made to this average, some holes appearing eccentric in one direction, others in the opposite direction. This method is especially effective for irregular-shaped parts, where edges are not parallel with any line of holes.

Orienting holes for grinding on a large diameter circle is another use for the rotary table, Fig. 233. In this case, the circle is too large for the short screw to encompass, yet it is desirable to locate the holes by *rectangular* coordinates because of the better accuracy anticipated, page 243.

The ring is set up on the rotary table and oriented to the average of the previously bored holes and the holes in half the circle ground. The rotary table is now turned through 180°. The last two holes ground are now indicated as a final check to insure turning exactly half way, and the holes in the second half of the ring ground. In case of an uneven number of holes, a new coordinate layout is not necessarily required for the second half, even in case of an uneven number of holes, provided the original layout is made to overlap so that the two end holes in the first half may be picked up after rotation.

GRINDING PROCEDURES

Outfeed Grinding — The term "outfeed grinding" is employed to differentiate it from "plunge grinding", described later. Outfeed grinding is the term used to designate the usual procedure in ordinary internal grinding, wherein the periphery of the wheel is fed into the work radially, a few thousandths or a few ten-thousandths of an inch at a time. Most of the cutting is done on the periphery of the wheel. This type of grinding is used in the Jig Grinder for finish cuts on most kinds of work.

Plunge Grinding — The term "plunge grinding", as employed here, Fig. 234, differs from its usual usage, wherein the face of a large wheel is fed, or "plunged" into the periphery of the workpiece. In the usage of the term as applied to the Jig

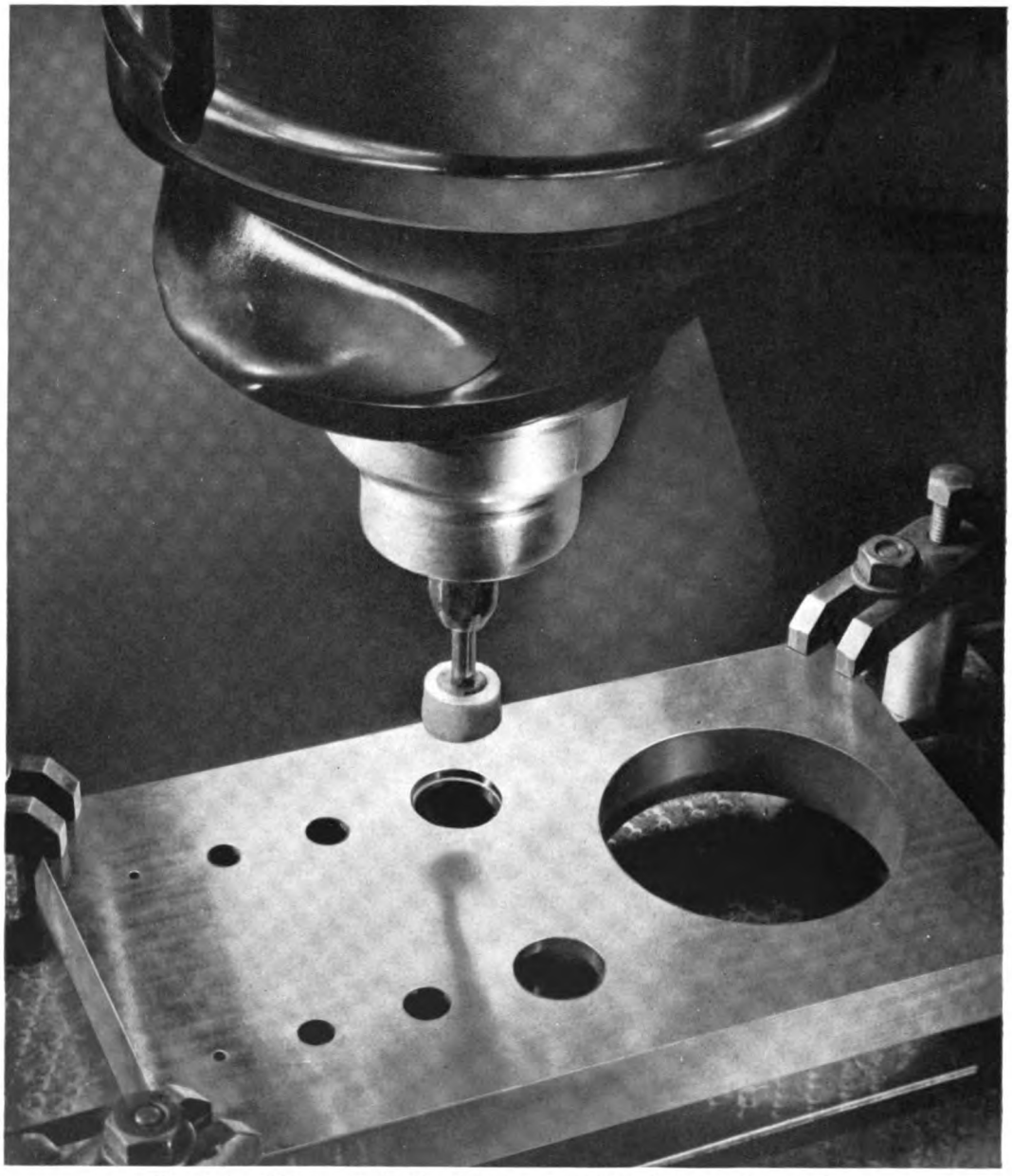


Fig. 234 — "Plunge grinding" offers extremely rapid method of stock removal.

Grinder, the bottom corner, or edge, of the wheel does the "plunging". This is a very rapid method of removing stock (see page 198), and, if the wheel is carefully dressed, produces sufficiently satisfactory finishes for some jobs. The sharp-cutting action which results from the small contact area, as contrasted with the rubbing, or abrading from larger contact areas, keeps the work cooler than conventional outfeed grinding.

The usual procedure in the Moore

method of plunge grinding follows:

1. Set the workpiece to the new correct location.

2. Dress the bottom face of the wheel slightly cup-shaped.

3. Offset the wheel enough to grind about 1/32" from one side of the hole.

4. With both the main spindle and the wheel spindle rotating, feed directly downward into the work. Feed slowly by hand to prevent overloading the wheel spindle.

5. Continue offsetting and plunging as above until the new size is nearly reached (within .002" to .003").

6. Re-dress the periphery of the wheel and bring the hole to size by conventional outfeeding (except in special cases, such as production work, pages 227 and 229).

This method is tough on the grinding wheel. The corner of the wheel may break down so fast that a new wheel must be used for sharpening up the square corner at the shoulder, if any, at the bottom of the hole. The time saved, however, far outweighs the value of the wheels consumed.

Grinding with Diamond-Charged Mandrels — We recommend the use of diamond-charged mandrels instead of conventional grinding wheels for grinding holes less than 3/16" or 1/4" in diameter, Fig. 235.

Before proceeding with the discussion of this technique, it should be clearly understood that the terms "grinding with diamond-charged mandrels", or "diamond grinding", as discussed here, are not "diamond lapping" and bear no relation to it. Cutting, in both cases, is done by particles imbedded in a matrix, but the similarity stops there. The action of a grinding wheel compares with that of a multi-point boring tool, while that of a lap resembles a reamer. Several basic differences establish a clear-cut demarcation between grinding and lapping:

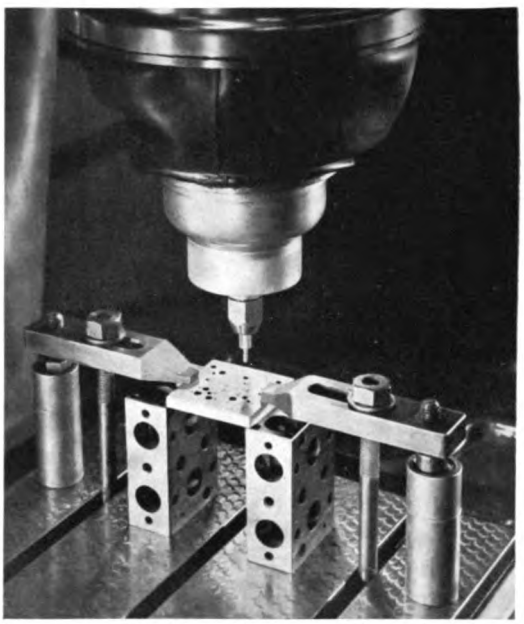


Fig. 235 — Grinding with diamond-charged mandrel. Besides achieving location, 0.150" hole was enlarged to 0.164" in 3 minutes.

1. In lapping, the lap is guided by the surface of the original hole, Fig. 236, and does not change the position of the axis of the hole. Grinding, however, permits correction of hole *location*, Fig. 237. The axis of any hole generated by grinding is established by the major axis of rotation, or axis of rotation of the main spindle.

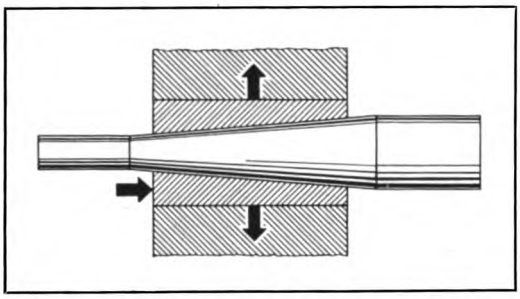


Fig. 236 — A lap cuts somewhat like a reamer; it follows the hole and cannot correct location. Hole size is increased (radial arrows) by driving lap axially along tapered arbor (axial arrow).

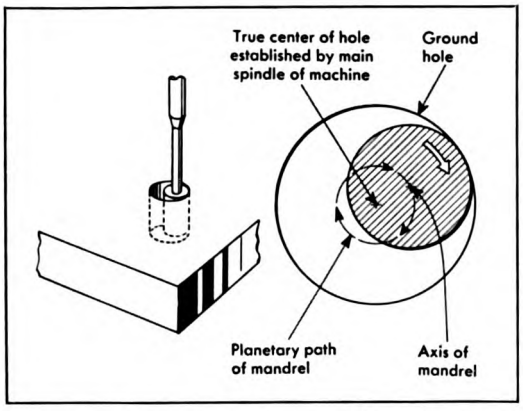


Fig. 237 — Planetary movement of Moore Jig Grinder permits correction of hole location. Hole size is increased by increased offset of axis of mandrel.

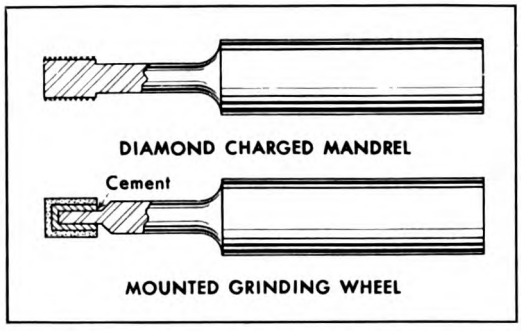


Fig. 238 — Stiffness of diamond-charged mandrel is greater than that of diameter of mounted grinding wheel. Hence, former can be run at optimum cutting speed of 1500 S.F.P.M.

2. A grinding wheel increases hole size by a movement outward from the major axis. In lapping, the radial expansion of the lap maintains its diameter with respect to the hole. This may be accomplished by driving the lap along its taper arbor, Fig. 236, or by splitting and spreading it with a set screw.

3. The surface speed of a grinding wheel is many times that of a lap, and touches the work at only a small arc of contact, while a lap is in contact over its entire circumference. It is not possible to lap at speeds fast enough to remove stock at grinding rates without excessive overheating.

4. The method of charging is also different. The lap is charged merely by sprinkling abrasive on it, trusting pressure from the workpiece to imbed it when the lap is pushed into the hole. Mandrels are charged by rolling or, preferably, hammering the dust into the surface, Fig. 244.

Grinding with diamond-charged mandrels is a true grinding operation, and should not be confused by the misnomer, "diamond lapping". The grinding of small holes with conventional grinding wheels is unsatisfactory for two reasons:

1. Lack of strength of grinding wheels of small size, Fig. 238.

2. Lack of any efficient mechanism capable of rotating them fast enough for efficient grinding.

Diamond-charged mandrels do not suffer greatly from the above limitations. Since they consist of particles imbedded in metallic mandrels, they are sufficiently strong to work efficiently in very small

holes. Toolmakers in watch factories employ them in sizes as small as .003″ to .005″. Moreover, if properly made and frequently cleaned, the particles remain sharp and free-cutting for much longer periods than those of conventional abrasive wheels.

The speed limitation, which severely hampers the grinding action of abrasive wheels, does not appear to interfere with that of diamond-charged mandrels. Abrasive wheels must operate at 5,000 or 6,000 surface feet per minute, while diamond-charged mandrels appear to do their best work at 1,500, and the loss of efficiency is not serious at speeds far below this. This is a distinct advantage, since it alleviates the problems attendant to extremely high-speed grinding spindles.

The cost of grinding with diamond-charged mandrels, as compared with abrasive wheels, is surprisingly low. The charged mandrel, including the diamond dust and the labor of turning and charging, Figs. 242 to 244, should not average over 30 cents. This compares favorably with the cost of the mounted point. The real economy, however, is in its cutting efficiency. At available speeds, the abrasive point removes stock slowly and requires frequent dressing. The diamond-charged mandrel removes stock at a very high rate.

The mandrel should be made from soft cold-rolled steel. Brass and copper charge easily, but do not have the required strength to hold the particles in place.

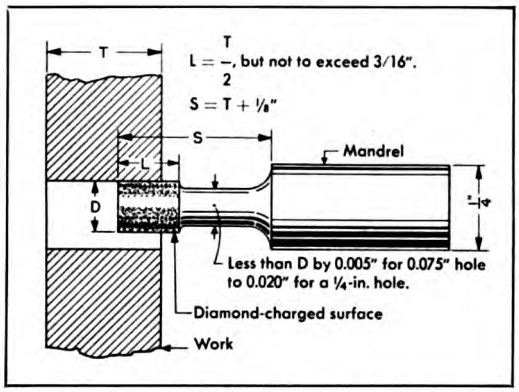


Fig. 239 — Experience with diamond-charged mandrels indicates that these proportions will give satisfactory results.

Optimum proportions of the mandrel are shown by Fig. 239. The shank is undercut slightly below the diameter of charged surface. A fillet at the junction of the shank and the undercut portion improves its stiffness. The length of the charged portion should be approximately one-half the depth of the hole to be ground, but should not exceed 3/16″, even in very deep holes.

We do not advocate the grinding of holes of a length or depth of more than six times their diameter. The stiffness of the mandrel will be so much reduced that great difficulty will be experienced in correcting the hole; the mandrel will bend and follow the existing surface, instead of correcting it.

The grinding mandrel may be likened to a cantilever beam, held rigidly at one end, the load at its free end represented by the pressure, or force, required to make the abrasive particles penetrate the work, Fig. 240. Grinding cannot be accomplished unless some force is applied, and any force,

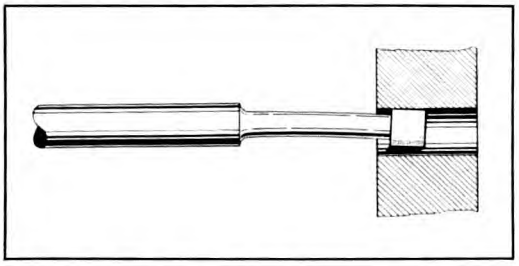


Fig. 240 — Grinding pressure, however slight, always deflects mandrel somewhat.

however small, will deflect the beam, however rigid. The amount of deflection is directly proportional to the force and inversely proportional to the rigidity, or stiffness, of the beam.

The formula for deflection of a round beam is as follows:

$$\text{deflection (at end of beam)} = \frac{F L^3}{3 E \left(\frac{\pi D^4}{64}\right)}$$

where F = the deflecting force, applied at end

L = length from point of support

E = modulus of elasticity of material comprising the beam

D = diameter of the beam.

Note from this formula that the deflection increases directly as the *cube* of the length, and inversely as the *fourth power* of the diameter.

We have no means of ascertaining specific unit pressures required to accomplish efficient grinding, either with diamond mandrels or abrasive wheels. We find experimentally, however, that when the six-to-one ratio is exceeded, rigidity of the mandrels and consequent efficiency of grinding decrease at an enormous rate.

As an example, let us take three hypothetical mandrels, Fig. 241, assuming an applied force F sufficient to bend, or deflect, mandrel A .0005″.

Reduction of the diameter from ¼″ to ⅛″, as in B, reduces its rigidity and, there-

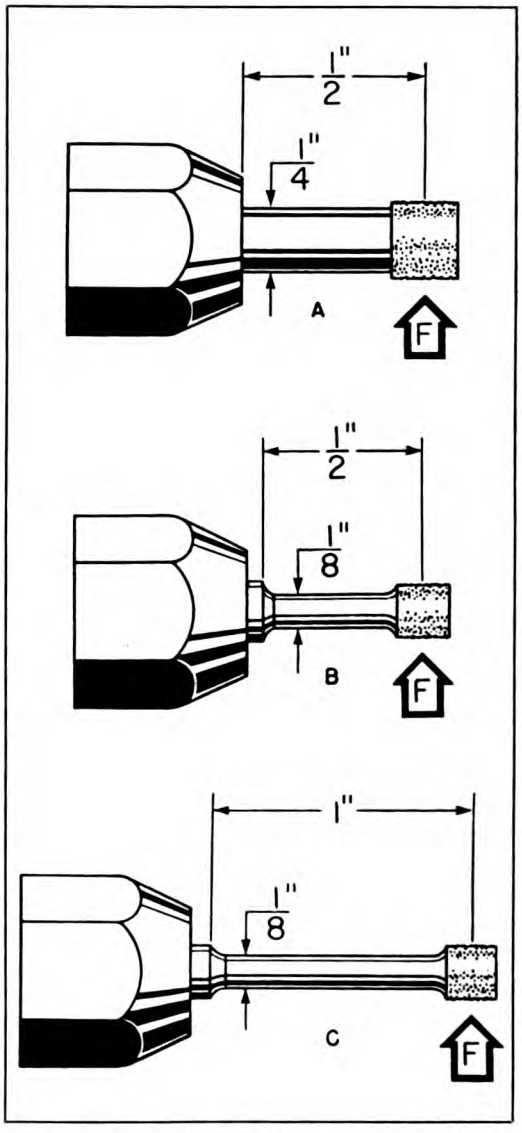


Fig. 241 — Deflection of mandrel increases sharply with decrease in diameter B, and pyramids with increase in length C. Same force required to bend mandrel A .0005″ deflects B .0005″ × 2^4, or .008″. Same force deflects mandrel C .0005″ × 2^7, or .064″.

fore, increases its deflection in the ratio of 2^4, or 16. The same force F will now deflect it 16 times as much as mandrel A, or .008″.

Doubling the length, as in C, increases the deflection again by 2^3 over B, or by 2^7 or 128 times that of A. The same force required to deflect mandrel A .0005″ will deflect mandrel C .064″, over one-sixteenth of an inch!

These cases are hypothetical since we do not know absolute pressures or deflections; they serve to illustrate the enormous *rate of loss* of grinding efficiency with slender mandrels.

The stiffness of the mandrel may be improved by keeping its diameter large in proportion to the hole, but this does not ensure grinding efficiency. The cutting part of the mandrel must always be larger than the clearance portion. As the cutting part approaches the diameter of the hole the arc of contact also increases, resulting in lower unit pressures and consequent loss of grinding efficiency.

The only other way of increasing the stiffness of the mandrel, that of employing a material of higher elastic modulus, is circumvented by the fact that a steel bar already has the highest modulus of any commonly known material.

These characteristics appear, at present, to limit definitely the practical grinding of holes to the above ratios.

In general, the mandrel should be as large as possible, leaving only sufficient clearance in the hole to permit straightening and to make sure the undercut portion clears. In large holes, such as ¼″, however, the mandrel need not be over 3/16″ in diameter to provide sufficient stiffness.

Required mandrels should be made before grinding is started, in order that grinding may be performed uninterruptedly. Look over your stock of mandrels first; maybe you already have those you need on hand. If not, analyze hole sizes carefully. You can probably use the same mandrel for several holes, if their sizes do not vary too much.

Figs. 242 to 244 show preferred methods of turning and charging the mandrels. Turn the working part of the mandrel first to correct diameter and length, Fig. 242. Advance tool bit into mandrel to make

Fig. 242 — Turn cutting portion of mandrel to size first.

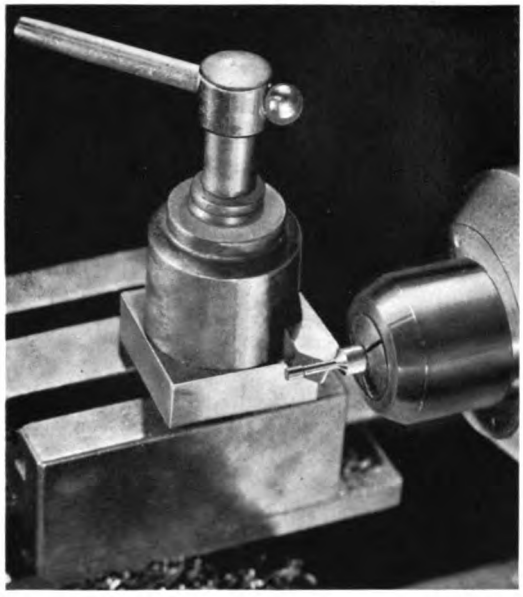


Fig. 243 — Advance tool, turn clearance portion in one cut. By this method thrust from cut is supported by entire bar.

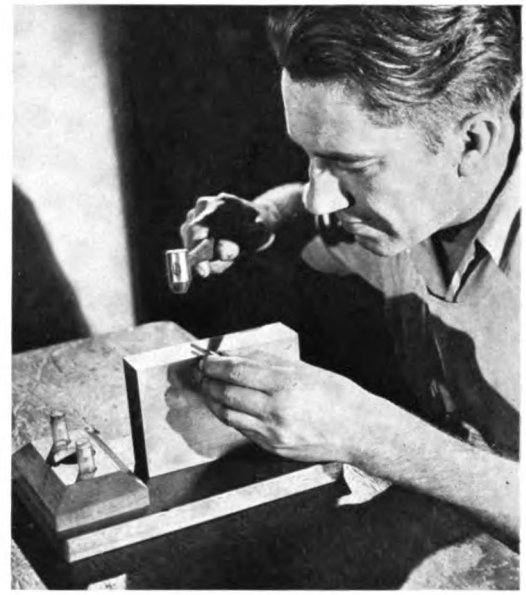


Fig. 244 — Hammering, rather than rolling, appears to produce a freer cutting mandrel, due possibly to more random placement of particles.

shank clearance (.002″ to .008″, depending upon size), Fig. 243, and turn shank to desired length (1/16″ to 1/8″ longer than depth of hole to be ground). The entire undercut portion of the shank is thus *turned in one cut.* This causes a certain amount of distortion, and, for this reason, the method may be questioned by toolmakers, since they may wish to take further cuts to true up the mandrel. The difficulty is that, after it has been turned to size, or nearly to size, it is not stiff enough to withstand the action of the cutting tool, and no correction is possible anyway. Final straightening is achieved after the mandrel is mounted in the grinding spindle by tapping it lightly with a hammer, Fig. 246.

For best results, the cutting portion should run true within .001″, or, at most, .002″. It is usually not necessary to test this with an indicator, however, since the operator can spin it with the fingers and estimate the high spot visually.

The term "charge" is used to differentiate it from "impregnation", which implies a uniform distribution throughout the mass, while in preparing the mandrel the diamond particles are driven in from the surface.

Although charging may be achieved by rolling the dust into the mandrel, hammering is preferred, Fig. 244. There are two plausible reasons for this:

1. A more random placement of sharp cutting edges. Hammering drives the particle straight into the surface, regardless of its position, while rolling tends to alter its position so that its largest flat surface, rather than a cutting point, is exposed.

2. Hammering does not appear to crush or pulverize the particles so much as rolling, and leaves stronger, more massive particles exposed.

Hammering tends to put "flats" on the mandrel more than rolling. Visual averaging of the finished surface, however, and straightening the mandrel ensures the presentation of a large proportion of the particles to the work.

To charge the mandrel, place a small quantity of dust on a hardened steel plate, moistened with oil to prevent the dust from flying around. Hold the mandrel about ⅛" away from the plate, and strike sharp blows with a hardened hammer. This drives diamond particles into both sides. Between hammer blows, rotate the mandrel slowly to expose and charge its entire circumference. Both the plate and hammer should be extremely hard, at least Rockwell 65C, to avoid charging them instead of the mandrel. After being charged, the mandrel should be dipped in acetone to remove any oil which may adhere.

Olive oil or other lubricants or coolants should not be employed while diamond grinding, since they tend to promote glazing and loading. Advice to the contrary should be disregarded; this advice stems from the misconception that diamond grinding is similar to lapping and from the fact that some diamond cutters use lubricants in their work. The action here is entirely different, and is a true

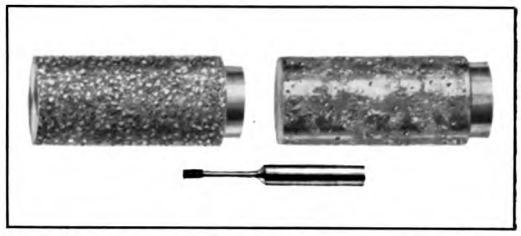


Fig. 245 — As seen with 10-power glass, surface of new mandrel (left) is well-coated with sharp diamonds. Right, mandrel after use. White streak reveals contact with hole.

grinding action. The mandrel and the hole should both be kept as clean as possible. A pipe cleaner, dipped in acetone, is a convenient method. Acetone has the quality of drying perfectly clean without leaving residual gums. Sometimes the Jig-Bored holes in a die block will contain scale and oil after heat-treatment. Make a pass or two with the diamond-charged mandrel and then clean the hole and mandrel with acetone.

The appearance of the mandrel after use provides no reliable indication of cutting efficiency. When first charged, the mandrel presents a dull gray appearance to the eye, but examination under a magnifier shows sharp cutting particles, Fig. 245. After use, it may be dull or shiny, but will still show sharp cutting points under the magnifier. The best measure of cutting efficiency is the operator's skill in judging whether the cutting action keeps pace with the feed.

If, after straightening the mandrel and taking a few passes, a shiny streak shows on one side, it does not run perfectly true, and should be further straightened with a

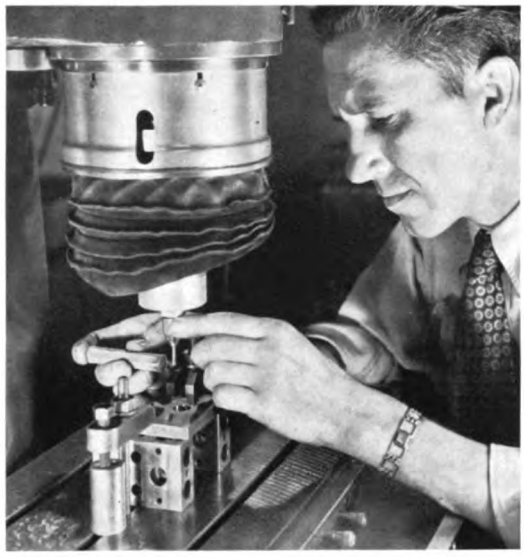


Fig. 246 — Mandrel may be straightened with tap of hammer or piece of brass.

tap of the hammer or brass rod, Fig. 246.

It is important to use the correct size of diamond particles. Diamond dust supplied for lapping is entirely unsuitable for charged mandrels. The latter require diamond particles which are approximately six times larger, sharp, and uniformly graded. A "coarse grade" of 60-80 grit should be used for roughing operations on holes of 3/32" in diameter, or larger. A finer grade, 80-100 grit, is required for finishing mandrels to cover this range, and is employed for both roughing and finishing operations on holes less than 3/32" in diameter.

The best results are obtained, both as to rate of stock removal and life of the charged surface, if a constant pressure is maintained between the mandrel and the work. Experience has shown that this amounts to about .0004"–.0005" lead of the feed over the cut until the hole nears size. This can be judged by the apparent rate at which the mandrel cuts, and generally an increase in feed of two or three "tenths" per stroke will maintain this ratio. Never let the mandrel run out at both ends of the hole; work the tight end of the hole by further run-out.

Obviously a freshly charged mandrel will remove stock at a much faster rate than one which has been used for some time. Caution should be used in recharging a mandrel just as a hole approaches size, because the rate of stock removal will increase greatly over that of a worn mandrel. Failure to consider this factor often results in grinding oversize before the mandrel can be withdrawn from the hole.

The following typical Jig Grinder procedure is currently employed in the case of three or more holes of a similar size:

Starting with a freshly charged mandrel, two holes are brought within .001"–.002"

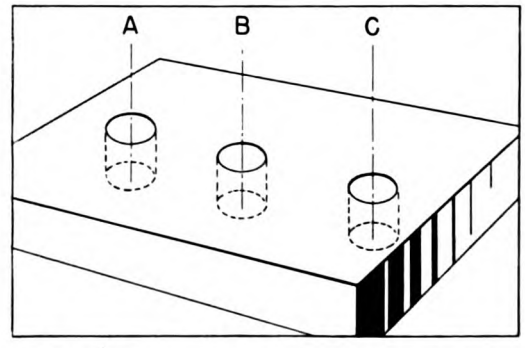


Fig. 247 — Proper method of grinding three holes is to grind holes A and B first within .001" – .002" and then hole C, within .005". Take new mandrel and finish C, thereby breaking down high points on tool, after which it is safe to finish A and B without cutting oversize.

of size, Fig. 247. By this time the diamond particles have been dulled and broken down to a uniform surface which cuts somewhat more slowly but produces a better finish. The third hole is now purposely ground .004″–.005″ under size. After recharging the now-worn mandrel, the third hole is brought up to size, taking the high points off the charged surface and reducing it to a uniform cutting surface before the last thousandth is removed. This minimizes the danger of using a fast-cutting mandrel in holes as close to size as the first two. The grinding rate of the mandrel will now remain constant for a considerable time and the first two holes can be safely brought up to size.

This technique is particularly adaptable to the Moore Jig Grinder because of the rapidity and accuracy with which the holes can be located in position for grinding. In any case, care should be exercised not to use a freshly charged mandrel when a hole nears size.

To eliminate bellmouth, reduce the offset before plunging mandrel into the hole, then advance while mandrel is in hole. Leave vertical stops set so the mandrel never entirely leaves the hole. To measure hole size, withdraw mandrel rapidly, and, after measuring, insert it again rapidly. How rapidly can best be judged from experience; there is no substitute.

Measure both top and bottom of hole as you go. Depend on graduations for coming to size when little stock is left. Check hole diameter with taper gage when coming up to size. Check with plug gage for *final* size, especially on precision work.

Do not permit the uncharged shank of the mandrel to come into contact with the hole. The frictional heat that will arise from the contact will burn the work and the mandrel. The work then can absorb diamond dust, and it will be practically impossible to reclaim the workpiece.

Amplifier and Insulated Parallels — Unlike a grinding wheel, the charged mandrel emits no sparks while grinding. For this reason, operators unaccustomed to their use have difficulty in ascertaining the exact moment they come into contact with the work. To facilitate this, the electronic amplifier, Fig. 221, may be provided. After a little experience, the operator can judge, from the appearance of the hole and the particles flying in the air around it, whether the mandrel is working properly. The amplifier then is no longer necessary.

Selection of Abrasive Wheels and Diamond Dust — A few general principles controlling the selection of abrasive materials are known. There is as yet, however, no sure-fire formula for selecting the proper grinding wheel for any particular job. For example, the general rule for soft materials of low tensile strength, such as cast iron or non-ferrous materials, is to use a hard abrasive grain, such as

silicon carbide, and a fairly strong or hard bond, the theory being that these materials do not dull or wear out the grains rapidly and that they should, therefore, be held in contact with the work as long as possible.

Unfortunately, silicon carbide grains are somewhat brittle, and so for grinding materials of higher tensile strength, such as steel, a tougher grain must be employed. Aluminum oxide is generally used for this. Some variation of aluminum oxide is usually found to grind most carbon steels and low-alloy, oil-hardening steels satisfactorily.

It is in the grinding of high-alloy hardened steels, such as high-carbon, high-chromium steels, that the most difficulty is experienced. These steels are coming constantly to the front for use in die-making because of their high resistance to wear and, for this reason, methods and materials for grinding them are a prime necessity. The aluminum oxide grains, although tough, are not hard enough to stay sharp. Silicon carbide, although hard and abrasion-resistant, is not tough, and particles break off the grains instead of cutting the steel.

The compromise usually employed is a hard type of aluminum oxide grain, held in a soft or weak bond, the theory in this case being that the grain should be ripped from its bond before it becomes dull, constantly exposing fresh, sharp grains.

The size of the grain also has an effect upon cutting action. Obviously, a large grain with a diamond-dressed flat top does not penetrate the workpiece freely. The cutting of coarse-grained wheels, therefore, especially under low cutting pressures, is slow.

Substitution of fine grains does not entirely solve this problem. Since there is room for a greater number of fine grains in a given space, *more grains* are brought into contact with the work and the pressure on *each* grain is reduced, reducing also its penetrating power. A partial answer is found by widely spacing the grains in the bond. This increases the penetrating power, of course, but each grain is then subject to excessive wear, and dulls rapidly.

Some deviation from the most efficient cutting speed of 6,000 surface feet per minute is also permissible by employing softer-bonded wheels at higher speeds, and vice-versa.

Effective hardness of the grinding wheel may also be altered by changing the ratio of wheel size to hole size. A small wheel presents a small arc of content, producing the effect of a softer hole.

Some of the difficulties are overcome by the use of diamond dust as an abrasive medium. Fairly coarse dust is recommended. Inaccuracies in manufacture and the lack of any method for dressing indicate that only a few grains are in contact

with the work anyway, and it is *better* to have those few firmly imbedded, provided their cutting points are good and sharp.

The final choice of grinding medium is dictated by many factors, interrelated, contradictory and difficult to evaluate. The opinion of a skillful and experienced operator is at present the most reliable guide.

Operators in our own plant have developed specifications covering most types of work. Recommendations are on a printed chart, available to users upon request. This chart is periodically revised and augmented to accommodate our current findings.

Although our stock of wheels is extensive, it naturally will not take care of the minute variations that may be required for production jobs, where, to attain the ultimate efficiency, wheels slightly different from our standard specifications may be desirable. Operators are encouraged to experiment. We shall greatly appreciate receiving reports of good results from wheels other than those we recommend.

Cooperation of Tool Designer and Toolmaker with Jig Grinder Operator — Cooperation between tool designer, toolmaker and Jig Grinder operator is a matter of vital necessity to all concerned. It may seem odd, inasmuch as the Jig Grinder is designed to help the toolmaker, that the toolmaker should now be solicited to help the Jig Grinder.

There are good reasons for this. Jig Grinder purchasers, before getting their machines and not realizing the many ways in which the machine can be of assistance, are at a loss to know how they can keep its capacity occupied. After a short time, the many uses become apparent, and the Jig Grinder suddenly becomes a bottleneck. Two or three machines are frequently required to keep abreast of a flow of work formerly done by other methods, or *left undone.*

Tools formerly made by hit-or-miss, one-at-a-time methods are now made on an interchangeable parts-and-assembly basis. All holes in die parts may be ground, including dowel holes. Mating holes in punch plates are Jig Bored, with full assurance of accurate alignment, without the necessity for transferring distortion errors and carrying them along through the whole job. The costly delay of making dies step-by-step is gone; all parts may be made concurrently to *dimensions.*

The quality of the tools is raised, too, by correcting errors from distortion. One of the greatest bugaboos, especially in multi-station dies, Fig. 211, is that of getting the die to *run* after it is built. Misalignment of punches and pilots causes cramping, chafing of pilots, and misalignment of shaving punches with previously-pierced holes. As a result, a great deal of tinkering is sometimes required to get any production from the die at all.

Multi-station piercing, shaving, and blanking dies must be accurate in many respects *even though high accuracy is not required in the finished piece part.* Among these are the following:

1. Piercing punches must align with die holes. This, of course, is axiomatic, as any toolmaker can readily appreciate. Any misalignment causes chafing of the piercing punches, with the attendant burred holes in the piece part.

2. Accurate spacing and proper use of pilot holes. This is of prime importance, especially when carrying the skeleton through many moves before final blanking of the piece part.

a. If all holes are not pierced in one station because of limited space, the relation of all holes in the blank will not be correct unless accurately piloted.

b. Misalignment causes chafing of pilots, shortening their life.

c. Jig-Grinding pilot holes in the *die* permits grinding them properly, in both die and stripper, instead of in stripper alone, as is frequently done. This gives the pilot better support, valuable in either thick or thin materials, for better strength and accuracy.

d. Accurate spacing of pilot holes assures perfect alignment of previously-pierced hole with subsequent shaving stations. Misalignment here is disastrous, whether in holes small or large in proportion to stock thickness. Its effect is to cramp the shaving punch sideways, chafing it against the die. In holes small in proportion to stock thickness, the sideways cramping effect is large. In thin stock, although the holes may be large, the clearance between the punch and die is small. Sideways cramping in either case is disastrous. When pressure on punches is purely axial, they will withstand enormous pressures; sideways pressures chafe and break them very easily.

e. Accurate location of pilot holes in blanking punch assures correct orientation of holes with contour of blank.

f. Assurance of high initial accuracy by grinding eliminates the temptation on the part of the toolmaker to "stake" punches, stripper bushings, or dowels, to correct location on a makeshift basis.

Drill jig, gage, and fixture bodies may be hardened, distortion subsequently corrected by grinding. This eliminates scoring and distortion from pressing bushings into soft bodies. Grinding of dowel holes assures repeated accurate location of tool parts. Some kinds of contours are ground to high precision. Parts awkward to balance in internal grinders may be Jig Ground. Machine parts may be hardened, bearing and pivot holes subsequently ground for accurate alignment.

In addition, the Jig Grinder serves as an important inspection machine, page 235, and part of its capacity is employed for this purpose.

Both the designer and toolmaker soon arrive at a realization of the Jig Grinder's capabilities. Not only does it permit time-savings and better accuracies; these features permit the designing and building of tools, especially dies, which otherwise could scarcely be made to perform.

As a result, the Jig Grinder becomes flooded with work. Designing and building of tools should be done with a view toward relieving the Jig Grinder operator and permitting him to do his part of the job as directly and economically as possible. Here are some of the ways in which both the designer and toolmaker can help:

1. Consult the Jig Grinder operator before and during the tool design period. He can frequently suggest ways for simplifying Jig Grinder operation. Try to foresee difficulties the Jig Grinder operator might encounter.

2. Pre-calculate Jig Grinder coordinate layouts. Usually the same layout employed in the Jig Boring is suitable.

3. Bush die and stripper where possible. This is good design policy and is already common practice in progressive toolrooms. This is done not merely to avoid the necessity for grinding to size, but to lengthen die life. Grinding the top of the die for sharpening increases piercing hole sizes due to draft. Concentric bushings may be replaced to bring the holes back to size. Die life may be further increased by making bushing holes deep, so new bushings may be replaced more than once.

4. Employ construction holes. Frequently there is so much distortion in a slender, irregular blanking hole, such as Fig. 38, that the template will not go back in after hardening without cramping or bending it. A pair of construction holes, located by Jig Boring before hardening, may be averaged, and the location of the group of piercing holes ground from the average of *both* construction holes. This assures the accuracy, among themselves, of the piercing holes. If the template fits the hole after hardening, it may be employed as the basis for the location of the group of holes, as in Jig Boring, Figs. 169 and 170.

In a multi-section die, Figs. 276 and 277, Jig Bore one or two construction holes in each section, each pair of holes in the same relation to its corresponding die station. These construction holes may be used for squaring up the sections after hardening, so that when all sections of the die are assembled together in the die shoe, all holes will be sufficiently accurate to clean up in grinding.

Construction holes are helpful in aligning die parts. Piercing punches should not be employed for this unless necessary, because of the clearance between them and the die. Jig Grinding promotes better alignment anyway.

5. Leave optimum grinding allowances. This does not necessarily mean the same

amount in all holes. In general, holes difficult to grind, such as deep, small-diameter holes, should have the least grinding allowances, while those large and easy to get at have the greatest. Parts may then be "juggled" around when setting up, to favor the existing location of difficult holes, grinding, if necessary, large amounts from easy holes. In general, on die work, .008″ should be left in each hole to be Jig Ground, but conditions are so much different in different jobs that a fixed allowance may get the operator in trouble. In long pieces, for example, distortion may be so great that this amount would not permit cleaning up. Better to leave more than this near the *ends* of long die parts, where the greatest distortion occurs, and less near the center. Of course, it may happen that the difficult-to-grind holes are at the end, in which case it may be better to split the die into sections.

6. In general, the toolmaker should not calculate that the Jig Grinder will finish-grind holes to size, especially holes carrying sliding parts, such as gages with line plugs, stripper guides, or parts bearing running shafts. Remember, the Jig Grinder is a grinding machine, not a lapping machine, and produces ground surfaces. Bearing or gaging surfaces should be lapped, just as they should be after being ground in any grinding machine. Holes may be lapped to size more accurately, with more certainty, and with less skill than they may be ground.

For this reason, the toolmaker should see to it that the Jig Grinder operator is furnished a plug .0004″ undersize for each hole to be ground, for use in checking hole size.

7. Plan to Jig Grind dowel holes. Interchangeability permits Jig Borer and Jig Grinder operators to plan their work and to fit it into their schedules when they can most conveniently do it, instead of at the exact moment when the toolmaker requires it. Jig Grinding dowel holes is helpful for another reason—the dowel always remains perpendicular, and subsequent grinding of mating faces will not alter location.

8. Avoid the design of too-deep holes, too small in diameter, pages 183 to 185. About six times the diameter is a reasonable limit. Beyond this, grinding mandrels become too slender, and are not stiff enough to correct location. Sufficient pressure to do any appreciable grinding bends the mandrel and makes it follow the original hole. It may be done by necessity, but the process is so slow and tedious as to be considered impractical.

9. Avoid working from finished surfaces which are easy to finish by Jig Grinding or other means, such as surface or cylindrical grinding. Temperature changes or vibration may cause a slight change in the position of the original pickup, after the machine has run. Better to take a cut on *every* surface in the Jig Grinder. For example, pilot holes *and* ex-

terior of round blanking punch, or piercing holes, *and* round blanking hole in die, may be ground. Stock may even be left on the outside of square or rectangular pieces, permitting "juggling" the piece around to clean up difficult-to-grind holes. Frequently *all* surfaces of parts of compound dies, Fig. 283 (right), may be Jig Ground to dimensions, including the outside diameters of round punches.

10. Where space limitations forbid the use of bushings, tapered holes may be ground in the die. In the case of small holes they should be taper-reamed from the back, to facilitate the grinding. Taper-ream carefully; make sure enough stock is left to clean up.

11. Final Jig Grinding of multi-station progressive die should be done with all parts assembled on their own dowels in the die shoe. Separate dowel holes, for attaching the stripper, are ground in the same set-up. This assures the best possible location of all holes with respect to each other, and eliminates the cumulative errors liable to be introduced by finish-grinding and assembling the die piece-by-piece.

12. Avoid designing tools with unnecessary precision dimensions — make tool so work can be done as nearly directly as possible from hole to hole, without intervening precision sizes. For example, in the 10-station progressive die, Fig. 211, pilot holes Jig Bored in the gutting station are picked up as reference points for grinding the pilot pin holes in the final blanking station.

13. Toolmakers sending work to the Jig Grinder should be sure it is *ready to be ground*. De-magnetize all pieces. Pieces squared up should be *square*, flat surfaces *flat*, lapped if necessary to insure good contact with holding devices and to prevent them from springing and warping when unclamped. Burrs and sharp corners should be removed. Sometimes special fixtures, Fig. 290, help the operator in making pickups. The designer and toolmaker should make every attempt to foresee difficulties.

Most piercing holes are left cylindrical for a short distance down from the top of the die, before starting the taper for draft. Some toolmakers prefer to lap this cylindrical surface to bring it smooth. Others prefer to leave the grinding marks in, contending that the roughness holds the slug and prevents it from withdrawing with the punch. The toolmaker should advise the Jig Grinder operator which he prefers.

Time Estimating — Time estimating for the Jig Grinder is best done by comparison with examples, rather than by a study of speeds and feeds, because so much depends upon the nature of the job and the keenness of the operator. Obviously, parts difficult to set up, containing only one hole, will require much more time per hole than directly-approached pieces containing many holes. This is especially true

if the several holes in the piece are the same size, since the same eccentric settings may be employed successively on all the holes, roughing, semi-finishing and finishing. In fact, the operator may go so far as to set up two or more parts containing the same-sized holes at the same time.

Conditions vary widely; it is impossible to make predictions covering each specific case. However, it is felt that our experience should be passed along to give prospective users as much assistance as possible. For this purpose, a few detailed time studies are shown. In addition, most of the subsequent photographic examples of operational practices show time estimates. A comprehensive mental comparison of the overall job, including setup and grinding time, with some other similar job, is a more dependable guide than a theoretical calculation from speeds and feeds, especially on tool work, where parts are made one at a time or, at best, in small quantities.

Production work is somewhat different, of course. Pre-calculation is a necessity, but usually must be based upon experimental data derived from tests simulating actual conditions. Total production, types of fixtures, speed of loading, accuracy and finish requirements, and gaging equipment are all governing factors.

The Jig Grinding sequence usually comprises three steps: Setting up, stock removal, and finishing to size.

Setting up and finishing to size are especially difficult to generalize, due to the wide variety both in types of work and accuracy requirements. Time is saved and better finishes result if holes are not ground to size, but subsequently lapped. To grind the last "tenth" requires about as much time as all the rest of the job. Ten to twenty minutes per hole may be required for grinding to a plug fit.

Stock removal, under average conditions, however, may be generalized. Approximately .001″ per minute of stock may be removed from the diameter of any sized hole in ordinary hardened carbon or oil-hardened tool steel, between .050″ and 1″ diameter, if the depth of the hole is not more than two or two and a half times the diameter and if the usual .008″ to .012″ is left for grinding.

At first glance, it may seem odd that all holes, regardless of size, may be ground at the same rate of speed. A little study shows why this is so. Heavy, fast-cutting wheels cannot be employed in holes as small as .050″. Diamond-charged mandrels are usually used. Although *total* stock removed by these mandrels is not so great as may be removed by large grinding wheels, the total internal area of small holes is also small; less total stock removal is necessary, therefore, to increase their diameters.

Conversely, as the hole size is increased, the internal area is also increased, *but*

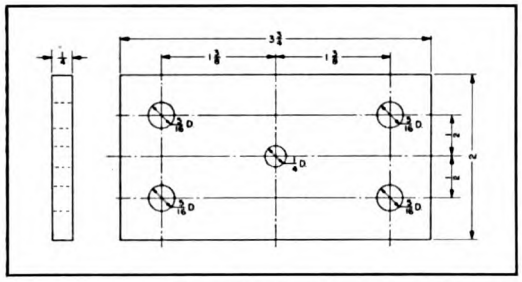


Fig. 248 — Dimensional details of master plate, Fig. 249.

there is sufficient room for large, fast-cutting wheels.

While the above figure (.001″ per minute) applies to average work in carbon and oil-hardening steels, high-speed steels and wear-resistant, high-chromium steels require about twice as much time.

Up to now we have considered average-sized holes. Deviations require more or less time, as the case may be. Holes 2″ in diameter, for example, may be ground at .001″ per minute, if not over 1″ or 1½″ deep. Holes 4″ in diameter, 1 to 1½″ deep, may be ground at about .0005″ per minute plus 5 to 20 minutes for finishing to size. If a hole is very deep in proportion to its diameter, the wheel shank or mandrel is necessarily slender, and the work is slowed considerably, especially in the high-speed and chromium steels. This may be expected in any grinder. In fact, when the hole approaches a depth of six times its diameter, cutting is slowed to the point where it is impractical. On the other hand, if the hole is shallow in proportion to its diameter, stock removal is faster. If a large amount of stock is to be removed, the operator can really hog it out, Figs. 234 and 250, by plunge grinding.

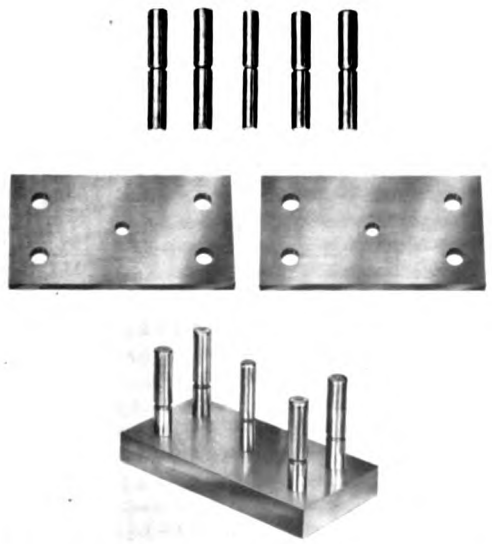


Fig. 249 — These plates are self-checking. Although Jig Ground separately, they will plug through in any of the four possible positions.

A few specific examples are helpful. All these are jobs actually performed and timed:

1. A pair of master plates, Figs. 248 and 249. Both plates exactly alike, oil-hardened tool steel, .010″ left for grinding, to be ground to plug gage size, without lapping. Both plates were set on the machine side by side at the same time, to permit the grinding of all holes of the same size successively with each eccentric setting of the grinding wheel. In the Moore Jig Grinder, it is not necessary to rough and finish one hole before proceeding to the next. Table settings by means of lead screws are so rapid that, once a wheel setting is found, movement to a new hole is quicker than making a new size adjustment.

Actual Time Study:

Setting up two plates on machine	45 min.
Stock removal (6 min. per hole)	1 hour
Bringing holes to size to plug gage fit, checking, etc. (12 min. per hole)	2 hours
Removal from machine, cleaning machine, putting away tools	15 min.
Total for two plates	4 hours

Note: Time for stock removal is lower than average; holes are approximately same depth as diameter; also nearly all holes are the same size. Time for bringing to size higher than average because of required high accuracy. Wring-fitting plugs could be inserted through both plates in any possible position.

2. Changing the location of a hole in a die by plunge grinding, section shown in Fig. 250.

Due to an error in Jig Boring, the center of this hole had to be moved .100″. .200″ of stock had to be removed from one side of the hole (cross-hatched portion). Material: oil-hardened steel. In grinding, the operator moved the work from the original location in successive steps of .075″, plunge grinding with the bottom corner of the wheel. One whole grinding wheel was consumed in roughing. Although tough on the wheel, the work was done very quickly; the cost of the wheel is a small matter proportionally. After roughing, a new wheel was employed to square the shoulder and grind both diameters to size.

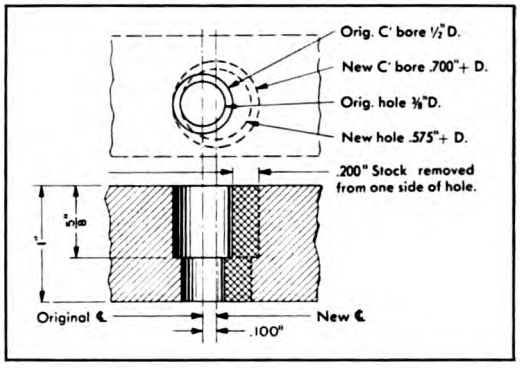


Fig. 250 — Plunge grinding provides rapid method for correcting hole by large amounts.

Time Study:

Setting up, establishing location	15 min.
Roughing out	35 min.
Squaring, cleaning both diameters (plug gage fit not required)	10 min.
Removal from machine, cleaning machine, putting away tools	15 min.
Total	1 hour, 15 min.

Note: Stock removal rapid because large amount of stock to be removed permits plunge grinding.

3. Grinding a large hole in a lamination die, Fig. 251. Material: high-carbon, high-chromium steel. Stock removed .035″. This is one of the toughest materials to grind, and a large allowance was left for grinding, because it is a part of a large die and because of the large distortion anticipated with this type of steel.

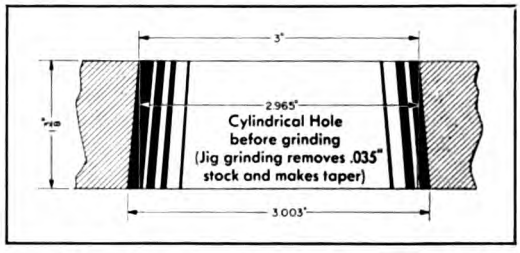


Fig. 251 — Dimensional details of large ground hole.

Time Study:	
Setting up	15 min.
Clean up hole, measure top and bottom to test taper setting	30 min.
Stock removal to within .001″ of size	2 hours
Final trueing of hole to size — check carefully for complete removal of bellmouth	1 hour
Removal from machine, cleaning machine, putting away tools	15 min.
Total	4 hours

Note: This job is slower than average because of the tough material and the care required to eliminate bellmouth. Grinding wheels glaze quickly on this material, and must be dressed about every other pass to maintain good cutting action. Dressing may be eliminated at the expense of grinding wheels by employing wheels as soft-bonded as possible, compatible with spindle speed and safety.

4. Diamond-Charged Mandrel grinding on production basis, Figs. 252 and 253.

When grinding small holes, especially when deep in proportion to their diameters, the grinding allowance is an important factor. If too little stock is left to grind, the holes may not clean up. If too much is left, an inordinate amount of time is consumed in the grinding. The best compromise between these extremes is determined experimentally. A few test pieces should be bored with various grinding allowances, hardened and carefully checked and ground.

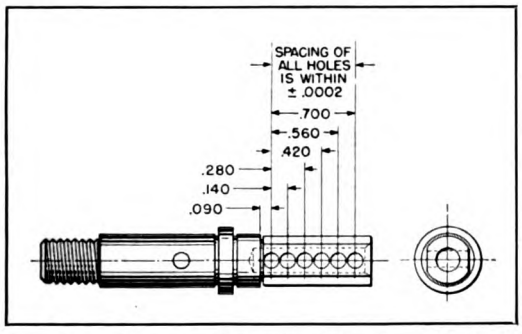


Fig. 252 — Dimensional details of Jig Ground holes in stud, Fig. 253.

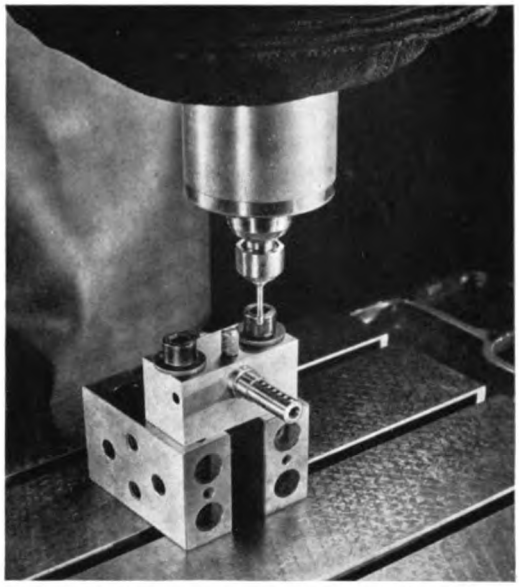


Fig. 253 — Stud set up for Jig Grinding.

Excessive grinding allowance works adversely in three directions:

(a) Excessive time consumed in actual stock removal.

(b) A smaller, less rigid mandrel must be employed when starting, especially when considerable hardening scale remains in the hole. A few thousandths on the diameter of the mandrel has an enormous effect on the stiffness of the mandrel — it goes up as the fourth power of the diameter, Fig. 241.

(c) Diamond mandrels require frequent re-charging. The time for this must be counted in the total.

Tests made on the workpiece, Figs. 252 and 253, emphasize these factors. Since this job was done on a production basis, the piece was held in a fixture, and setting up each piece consisted of loading and checking the location of only one hole, assuming that, this hole being correctly located, all others would clean. Loading time is included in time analyses.

Some examples were made with .006″ to .008″ left for grinding. Grinding consumed 4½ to 5 hours per piece, nearly ¾ hour per hole.

Others, with only .003″ to .004″ left for grinding, were ground satisfactorily in 2 hours per piece, or about 10 minutes per hole.

In the second case, extra care had been employed in the Jig Boring, both as to location and size of the hole in the annealed state. Great care was taken to assure uniformity of material and heat treatment. This extra care involved some extra time in preliminary operations. In spite of this, the overall saving was clearly at least two hours per piece. On fifty pieces, a saving of two weeks' work! There seems to be no better way to determine optimum conditions except by experiment, definitely worth while, however, on a job of this magnitude.

Operational Practices by Example — Actual examples provide the best explanation of specific operational practices. Although this book is intended to be of a generalized nature to suit any make of Jig Borer, the Moore Jig Grinder is the only machine of its kind, and instructional material must be written specifically around it.

The first example will be that of the die shown in Fig. 31, made to precise specifications for cutting thin stock. Dimensional locations of holes in die must be accurate to produce accurate blanks, and alignment of punches must be held to high accuracy because of the small clearance between punches and dies.

Select a suitable place on the table for the work. In general, the work naturally is located near the center of the table, but there are advantages in placing it near the ends or corners, in that it tends to equalize wear over the entire table surface and also over the entire travel of the ways. Another advantage in placing work near one end is that if an emergency job comes along, it can be placed near the other end, without removing the first job, going back and finishing the first job after the emergency job is done.

Select suitable parallels. Inasmuch as it is sometimes necessary to measure the *bottoms* of holes, make sure the parallels are high enough. At any rate, use parallels high enough to get one of the air inductors under the piece, Fig. 255. Parallels should be wide or thick enough to prevent tipping, and have enough supporting surface to prevent them from indenting the table.

In case of long workpieces, where there

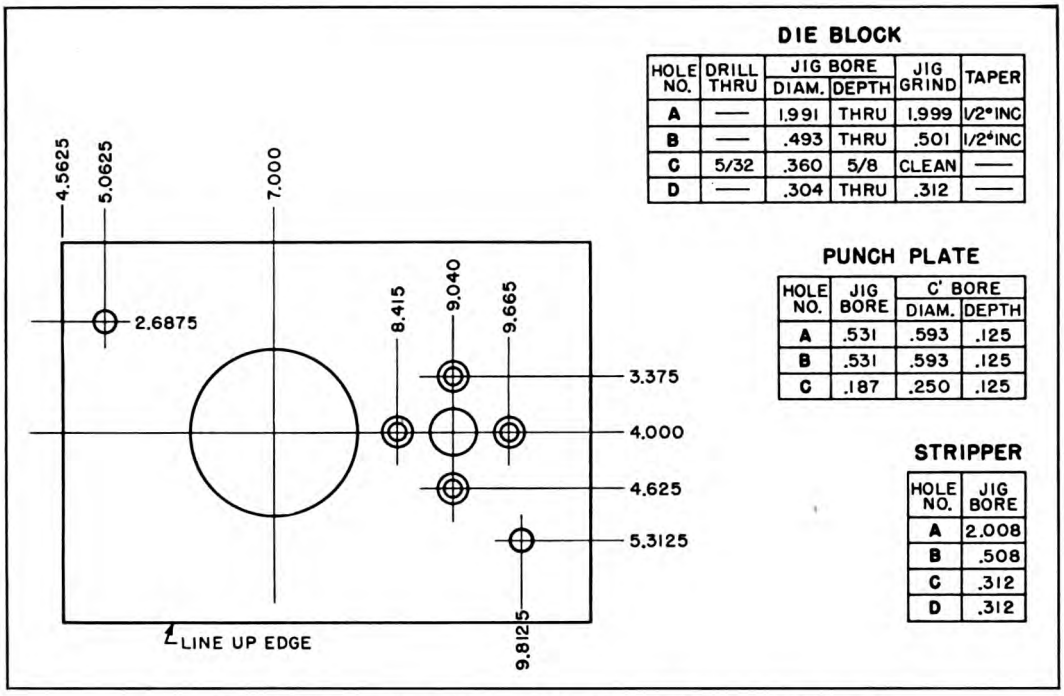

DIE BLOCK
HOLE NO. | DRILL THRU | JIG BORE DIAM. | JIG BORE DEPTH | JIG GRIND | TAPER
A | — | 1.991 | THRU | 1.999 | 1/2° INC
B | — | .493 | THRU | .501 | 1/2° INC
C | 5/32 | .360 | 5/8 | CLEAN | —
D | — | .304 | THRU | .312 | —
PUNCH PLATE
HOLE NO. | JIG BORE | C' BORE DIAM. | C' BORE DEPTH
A | .531 | .593 | .125
B | .531 | .593 | .125
C | .187 | .250 | .125
STRIPPER
HOLE NO. | JIG BORE
A | 2.008
B | .508
C | .312
D | .312
4.5625
5.0625
7.000
2.6875
8.415
9.040
9.665
3.375
4.000
4.625
5.3125
9.8125
LINE UP EDGE

Fig. 254 — Modern coordinate layout for die in Fig. 31. Contains all information necessary for both *Jig Boring and Jig Grinding.*

is danger of sagging, use three parallels, or parallel setup blocks, made in sets of six to provide an adequate number of supporting points. Also avoid placing the parallels under holes which are to be ground.

Arrange for clamping directly *over* the points of contact with parallels — do not apply straps over spaces where there are no parallels, since lack of support is sure to spring or warp the piece. The small pressure of the tightening wrench exerts tremendous force on the bolts, springing both workpiece and machine table. Watch carefully for burrs on work, parallels, or table, to prevent wear and scratching of table top. Burrs may be removed with a small, fine-grained pocket stone. The heel rest and heel adjustment should be such that the strap will be level, to avoid side strain or twisting. Keep the bolt near the work, not near the heel rest, to localize stresses directly through parallels.

The coordinate location sketch for this job, Fig. 254, is similar to that in Fig. 204. The same sketch may be employed for both Jig Boring and Jig Grinding, regardless which holes are picked up. Scales and dials may be set to the same figures as were used on the Jig Borer.

The indicator clamp ring, holder, and indicator are next assembled to the grinding head in such a manner that the indicator point contacts the work on the same side as the grinding wheel will subsequently bear — opposite the oval adjustment hole in the aluminum dust guard.

This compensates for minute variations from roundness of main spindle bearings. Set the main spindle housing at such a height that grinding wheels may go through the work and yet be withdrawn sufficiently to measure hole sizes without disturbing it.

The operator must next determine which holes must be held to size. In this case, they are the blank hole and the center piercing. It is essential that both these holes clean up, and that their center line be parallel with the edges of the die.

Either of two courses may be followed to attain parallelism:

1. The edges of the die may be indicated parallel, Fig. 255, and the holes ground parallel to them, or

2. The holes themselves may be indicated parallel, and spots, or shallow scallops, ground in one edge in the same setting used to grind the holes. These scallops may be indicated, workpiece being held on the surface grinder, and the edge ground parallel to the scallops. The ends of the die need not be ground since they are not used. When the die has been set up parallel by one of the above methods, tighten straps carefully and prepare to re-indicate the holes for optimum orientation. While indicating, the main drive clutch should be disengaged, to free the spindle from the drive motor. The drag of the motor is liable to resist rotation to such an extent that the additional hand pressure required will spring the spindle away from its true center of rotation. In general, the clutch should be used for this purpose only, not for starting and stopping the machine. The control switch is intended for the latter.

Fig. 255 — Indicating edge of die parallel. One strap left lightly clamped to permit tapping end of die with hammer to bring it parallel.

In addition to being parallel with the die edges, the group of holes must be accurate among themselves. The problem now is just where to place the piece in the co-ordinate location system. Assume that heat-treating distortion and other errors have shrunk dimension 2.040″ in Fig. 31 to 2.038″, a shrinkage of .002″.

Either of two courses is then possible:

1. To pick up the center piercing hole, setting the longitudinal and cross scales and dials to 9.040″ and 4.000″ respectively. The piercing holes, being close together, could clean up with a minimum of stock removal. The main blanking hole, and the

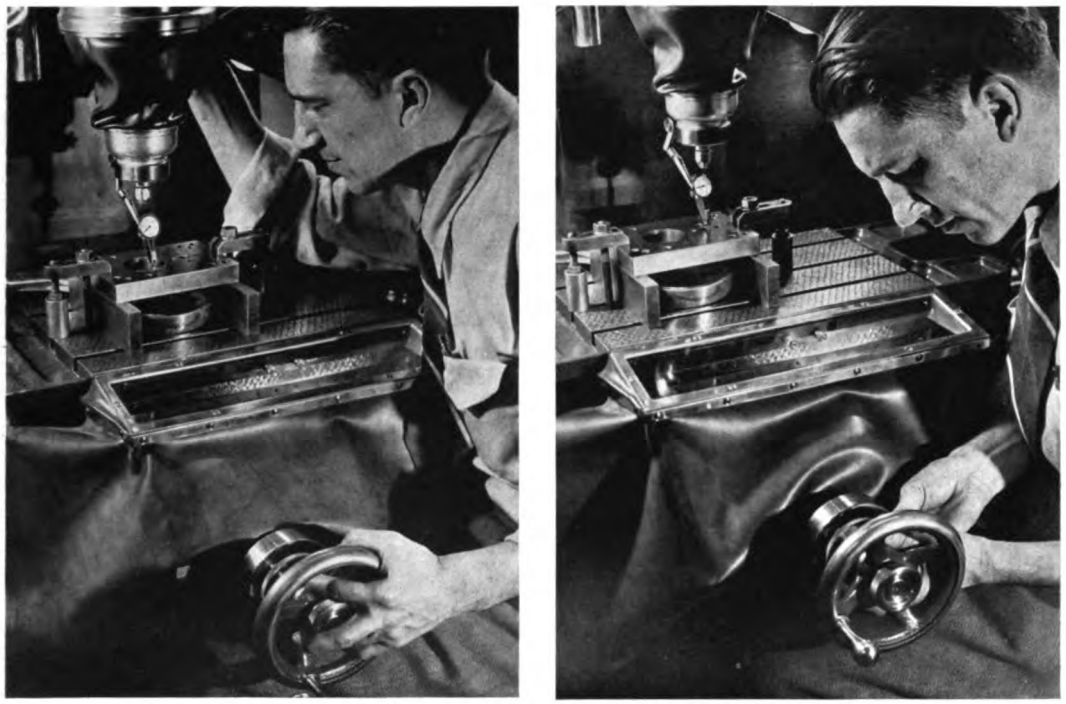


Fig. 256 — Pick up blanking hole and center piercing hole, setting scales and dials to average error between them.

dowel hole farthest away would have to be moved .002″ and approximately .004″, respectively. This would be excessive, especially for the dowel hole. Since an amount of stock equal to twice the correction must be removed, Fig. 250, the dowel hole must be enlarged by at least .008″ to clean it up. Merely cleaning up is not sufficient, either; enough stock must be removed from the low side to get under the scale and insure uniform grinding conditions.

2. To pick up both the main blank hole and the center piercing hole, averaging the error between them, Fig. 256. Scales and dials, therefore, will be set so that the reading on the longitudinal scale and dial for the blanking hole will be 7.001″, or .001″ plus from the coordinate layout, while that for the center piercing hole will be 9.039″, or .001″ minus. On the cross screw, both holes will read 4.000″. This will insure all holes cleaning up with a minimum of stock removal.

Notes on Grinding Sequence — In deciding the sequence for grinding the holes in any specific job, the operator should consider the following:

1. In general, *all* holes should be rough-ground before *any* is finished. This minimizes the effect of thermal or other changes.

2. All holes whose interrelation are most important should be finish ground within a continuous period of time. If all

holes cannot be finished during the same working period, or on the same day, determine which may be left for the next day.

3. In dies, where draft is to be ground, avoid changing back and forth from taper setting to cylindrical. This consumes a certain amount of time, and interferes with the directness of grinding all holes within a short period of time.

4. Avoid grinding holes with shoulders twice, since this necessitates making accurate depth settings twice.

5. Avoid changing grinding heads as much as possible. This cannot always be avoided when extremely high or low speeds must be used on the same job, but it can usually be arranged that not more than one change is necessary.

Not all these considerations are compatible, so a little forethought is sometimes necessary to reduce their ill effect.

In this die, for example, the holes most important to interrelate accurately are the main blanking hole, the center piercing hole, and the two stripper dowel holes. They must all be held to size, since they cannot be bushed, and the dowel holes are to match dowel holes in the stripper, independently Jig Bored to dimensions. These four holes, then, should be finish-ground uninterruptedly.

The following sequence, on this job, meets the major requirements:

1. Rough (cylindrically) blank and center-piercing holes.

2. Rough and finish-grind four bushed holes. This avoids making two depth settings.

3. Rough and finish dowel holes: These must be carefully done, since the stripper guides the small punches, and clearances are small.

4. Finish-grind blank and center-piercing holes cylindrically to size.

5. Set vertical slide to taper, finish-grind taper in main blanking hole and center-piercing hole.

This sequence finish-grinds consecutively the four most important holes, requires only one setting for bottoming the shouldered holes, and requires only one taper setting.

There is a great difference between the sizes of holes in this piece and, obviously, different-sized wheels. Therefore, different speeds should be employed. Since it is inconvenient to change heads during the same job, however, the point of efficiency will be stretched, and all holes will be ground with the 50,000 RPM head. Some slowing of head speed is attainable by reducing air pressure and a deviation from proper grinding speed is permissible by using softer — or harder — bonded wheels. A chart showing speed-pressure relationship is also available.

A grinding wheel of proper grit and grade should be selected. It should be approximately ¾ of the diameter of the hole, although a wide range of compromises from this is permissible.

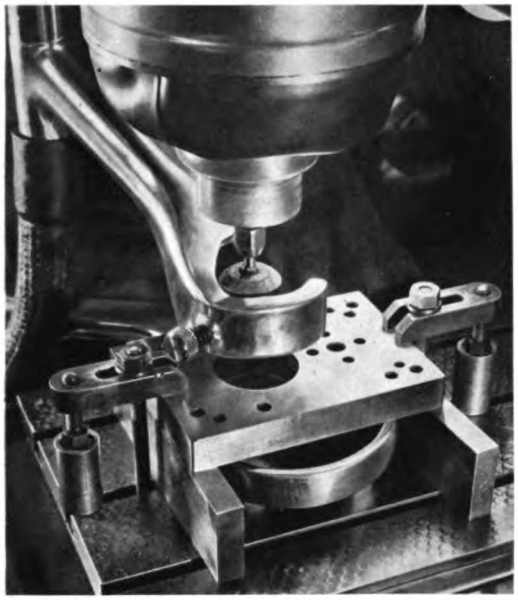


Fig. 257 — Wheel-dressing arm. Diamond, mounted on end of knurled screw, is adjustable.

Fig. 258 — Hand-held diamond block for places inaccessible to arm.

Do not permit the wheel to project any farther from the chuck than necessary, Fig. 258. For safety reasons, do not immediately start the grinding wheel up to full speed. Start it to about half speed, dress the wheel true, then carefully advance to grinding speed.

Two facilities for wheel dressing are provided, Figs. 257 and 258. The diamond dressing arm, Fig. 257, provides fine adjustment and means for sucking the dirt away.

Since the wheel is sometimes inaccessible to the dressing arm, a diamond-holding block is also provided, Fig. 258. Hexagonal in shape to provide many angles of approach, it equalizes the diamond wear and always presents a sharp point. Rested on the work, it is moved by hand to contact the wheel. Standing the block on its end permits dressing with the wheel only slightly withdrawn from the hole.

Usually the full wheel face is not employed; it is cleared away so only about ¼″ of the face does the work, Fig. 259. Wheels

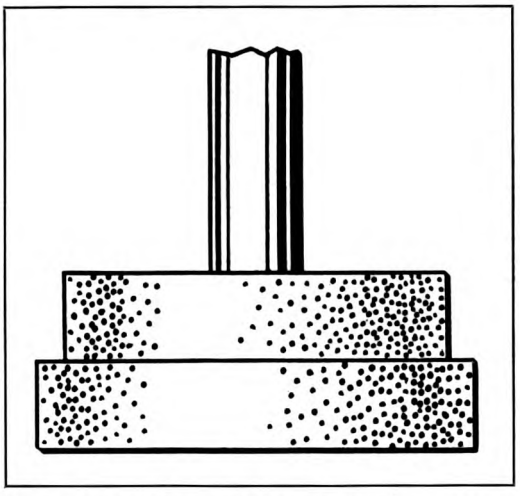


Fig. 259 — Too-large grinding wheel contact areas require excessive cutting pressures. Clear away all but about ¼″.

Fig. 260 — Dressing wheel with carborundum stick.

smaller than ¼″ are usually held on ⅛″ shanks, although smaller shanks may be provided by turning down ¼″ shanks, Fig. 260. Wheels on ⅛″ shanks are usually more easily dressed by a hand-held carborundum stick, since the rigidly held diamond is liable to start them chattering.

Before attempting to do any grinding, back off the fine-range adjustment, Fig. 261, nearly to the top of its travel. The entire range of fine adjustment is then available, after making the rough adjustment, Fig. 262. While making the rough adjustment, rotate the main spindle by hand to make sure the wheel does not quite touch the high spot (nearest part of hole to rotation center).

For grinding through holes, set the positive vertical stop, Fig. 263, so that the wheel projects about half its length out of the bottom of the hole. Since the vertical slide may accidentally be set to grind a taper, the main spindle should again be rotated by hand to make sure the wheel does not hit the bottom of the hole, that the collet does not hit, or that some rotat-

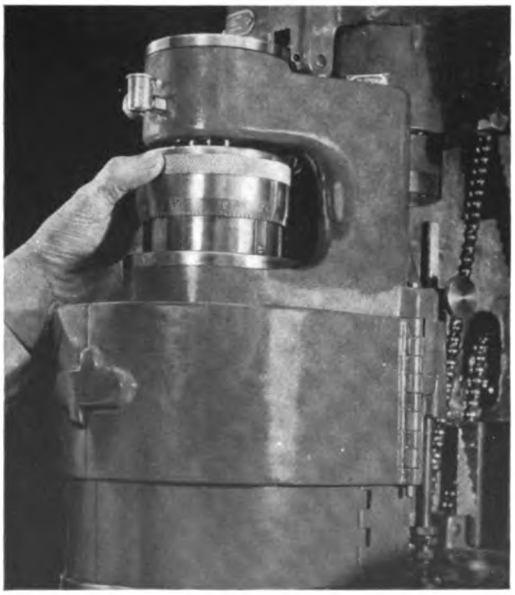


Fig. 261 — Start job with fine adjustment backed off. This provides for use of entire range during grinding.

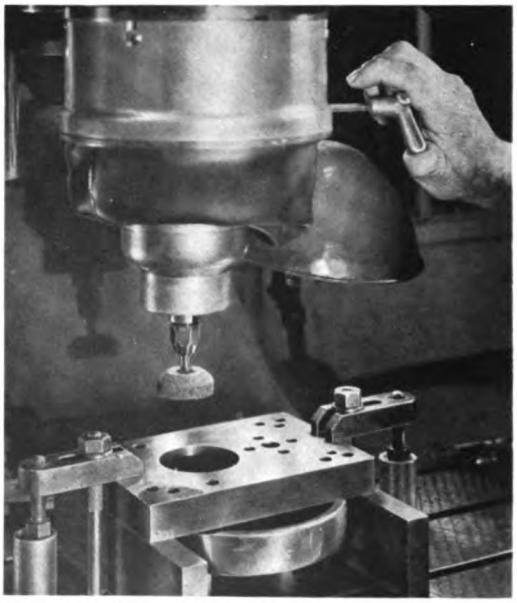


Fig. 262 — Rough adjustment made with wrench through oval slot.

Fig. 263 — Vertical stop prevents over-travel of wheel.

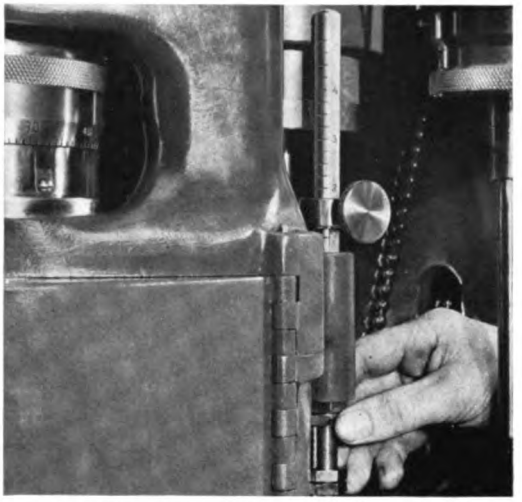


Fig. 264 — Setting trip nut to limit down-feed.

ing part cannot hit a possible projection, such as a die post, bolt or strap.

We are now ready to grind.

Withdraw wheel from hole.

Throw in clutch.

Throw starting switch on.

Start grinding spindle.

The planetary motion has now started, the main spindle and grinding spindle rotating above the hole.

Feed down slowly into the hole by hand, to make sure nothing hits. When near the bottom of the hole, feed outward with the fine-feed control knob until contact is made between the wheel and the hole. Continue feeding, up and down by hand or automatic feed (see below) until the hole is cleaned up, or roughed, to desired size.

To set automatic feed:

Feed down by hand, setting trip nut, Fig. 264, by cut-and-try, until the power feed trips just before the positive stop acts. Power down-feed will now always be stopped and reversed at the proper moment. To stop and reverse power up-feed at the proper moment, allow the machine to feed up until the wheel just clears the top of the hole. Throw the hand knob to feed down, and immediately tighten the trip collar, Fig. 265. The machine will now

Fig. 265 — To limit up-feed, tighten knurled screw in trip collar.

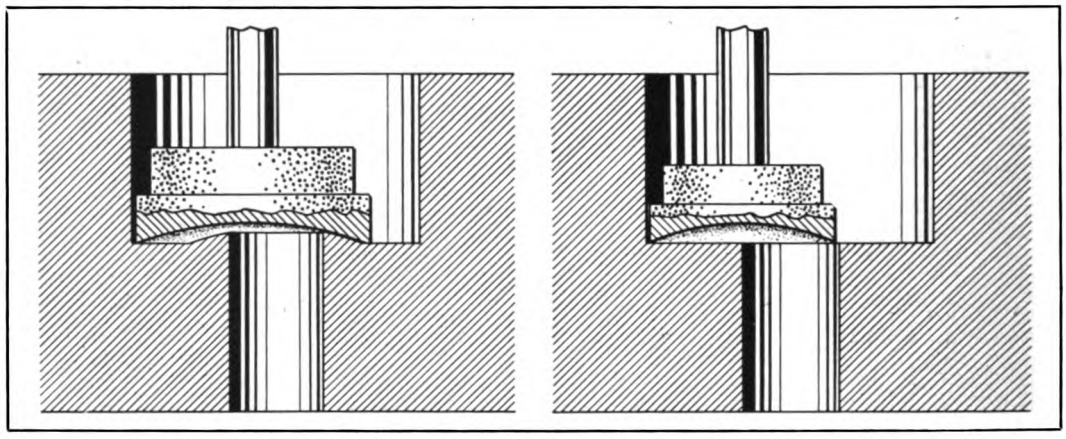


Fig. 266 — Left, if grinding wheel is too large shoulder will not grind flat; must be small enough to clear back side of hole, right.

feed automatically up and down through the proper distance. The main blanking hole and the center piercing hole are to be roughed by this procedure.

Never disturb the setting of either pair of lock nuts on the vertical trip rod, immediately above and below the spindle housing. These are safety devices, factory set, to prevent damage to the power feed mechanism by over-feeding.

Grinding to shoulders:

Select a wheel *small* enough that back of wheel will clean up shoulder, Fig. 266.

Release positive stop, re-set it so wheel just hits bottom of hole. Rotate it slowly by hand to feel contact. Lock the stop in this position and back it up so wheel clears by turning the limiting screw.

Start machine, advance eccentric adjustment until wheel hits side of hole, back off depth stop until wheel hits shoulder. Grind sides and shoulder of hole at the same time, to eliminate possibility of a double shoulder. Continue grinding, backing off the limiting screw slightly at the bottom of each stroke, to compensate for wheel wear, until hole is cleaned up. Clean up all holes in this manner, bringing them all to the same size as indicated by graduations on the control knob.

After roughing, dress the wheel again to a true cylinder and proceed to grind both shoulder and side of hole until the correct size is attained.

The stripper dowel holes may next be roughed and finish ground to lapping size. This is contradictory, since we have previously stated that *all* holes should be roughed before any is finished. In this case it is done as a compromise to avoid retracing steps. .0003″ to .0005″ should be left in the dowel holes to permit lapping to size. This smooths off the ridges left from grinding. Subsequent driving in and out of the dowel pins will not burnish or wear the holes oversize.

The main blanking hole and center piercing hole are now finish ground to size,

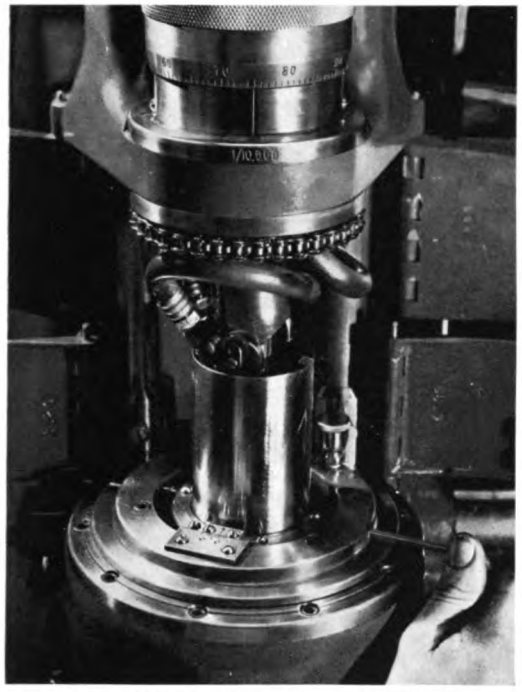


Fig. 267 — Taper setting is achieved by adjusting two opposing set screws. Amount of taper is read from graduated plate.

cylindrically, before setting the taper adjustment to grind the draft. The next, and last, grinding operation consists of grinding the taper, or draft, in these holes. They are to be left straight or cylindrical for about ⅛″ at the top.

Set taper control; read correct amount from reference plate on top of main spindle, Fig. 267. Taper setting is achieved by turning the two opposing hollow set screws, loosening one, tightening the other. Do not tighten these screws too much; excessive pressure may squeeze the guide sleeve out of round, causing it to bind the vertical slide. Make sure the taper is set in the correct direction. With the reference plate facing the operator, grinding is done with the left-hand side of the grinding wheel, *opposite* the rough adjustment slot in the aluminum guard. To taper the hole larger toward the bottom, therefore, the zero plate must be moved to the right.

Warning: The taper setting will now cause the wheel to hit the side of the hole near the bottom. Back off the rough adjustment again, and advance wheel through hole cautiously, by hand, without power, to make sure the wheel does not hit, turning wheel spindle by hand. Advance rough adjustment until contact is nearly made.

Withdraw wheel from hole, start machine, as on page 207, and lower wheel into hole cautiously, by hand, to bottom of hole. Advance offset until wheel makes contact. Go ahead and grind. At first, because of the taper setting, the wheel will grind only at or near the bottom of the hole. As material is removed and the offset adjustment is advanced, grinding proceeds nearer to the top of the hole. Continue until sufficient cylindrical surface remains. This may be determined by watching the difference in appearance between the tapered and cylindrical portions.

Both the main blank hole and center piercing hole may be ground in this manner, completing the grinding of the die block. In the hands of a good operator, this die should be set up and ground complete in 3½ hours.

Since the die is Jig Ground to dimen-

sions, including the dowel holes, it is unnecessary to transfer the holes to the stripper and punch plate. Instead, they may be Jig Bored, also to dimensions. The punch plate is Jig Bored, as in Fig. 168. The stripper need not be mounted on the die block, as in Fig. 167, but may be placed on conventional parallels. Both are Jig Bored to standard figures, Fig. 254, with no allowance for heat-treating errors. Jig Grinding of the die block and Jig Boring of the stripper and punch plate may be performed concurrently.

All parts Jig Bored or Jig Ground should be inspected for location before removing from machine. Call the inspector, check over the figures on the coordinate layout, and indicate each hole. See also pages 235 to 246.

Another Method for Taper Grinding — Many holes in dies have ⅛″ or so of cylindrical, or straight, section at the top before the draft starts. When holes are large and accessible, like those in the die previously described, the entire depth of the hole may be ground cylindrically and measured for size at the top before grinding the tapered part. The taper grinding can be watched as it is ground nearer and nearer to the top, stopping when sufficient cylindrical surface remains.

When holes are small and inaccessible, the problem is different. The grinding wheel or mandrel largely fills the hole, and it is impossible to determine visually how far the taper extends. To overcome this difficulty, the hole is first taper-ground all the way to the top. The diameter at the top is measured with a taper gage or plug. The machine is then set for cylindrical grinding, and the top end of the hole ground to its correct finish diameter. If the correct size has been ground at the top end of the taper, this method automatically provides a cylindrical surface to the correct depth.

The problem lies in knowing the proper size for the top of the original tapered hole. It may be calculated from the

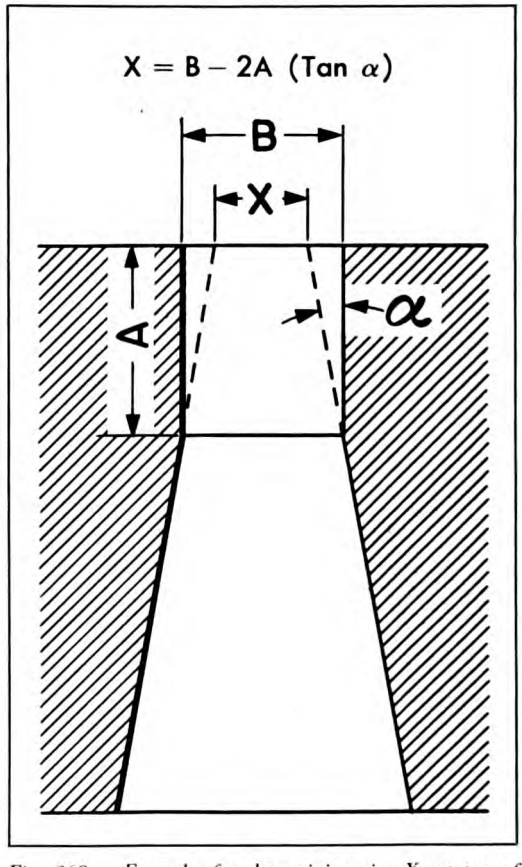


Fig. 268 — Formula for determining size X, at top of tapered hole to produce desired depth of cylindrical section A.

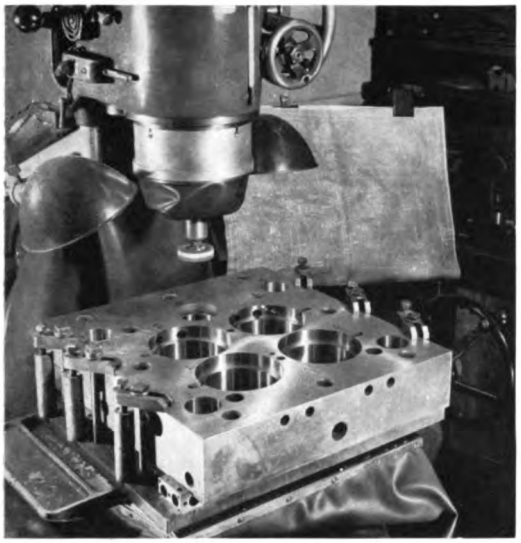


Fig. 269 — Grind two pin holes, four center holes. Turn around, grind injector holes, two remaining pin holes.

formula X = B–2A (tan α), Fig. 268, where:

X = desired diameter at top of taper as originally ground.

A = desired depth of cylindrical portion of hole.

B = diameter of finished cylindrical portion.

α = angle of taper (one side).

Grinding Die Larger Than Machine Travel — The holes ground in the mold die, Fig. 269, consist of four guide pin holes, four cavities, and one injector hole, easily discernible in the photograph. Distances between holes exceed the cross travel of the machine. Obviously this cannot be ground in a single setup. Two pin holes and the four central cavity holes are ground in one setup, then the piece is turned around. The two accessible cavities are picked up to orient the piece in the coordinate location system for grinding the remaining two pin holes and the injector hole.

The four pin holes are 1¼″ diameter x 3″ deep.

The four cavity holes are 4⅛″ diameter x 2½″ deep, having counterbored sections 4⅞″ diameter ground to exact depth, .500″ ± .001″.

The injector hole is 2¾″ diameter x 2½″ deep. Due to its large size, excessive amounts were left for grinding, approximately .025″ in all diameters and 1/64″ on the shoulders.

Thirty-five hours were consumed in the grinding. This does not indicate too efficient grinding; in fact, considerable difficulty was experienced, largely because of the great depth of the 1¼″ pin holes, necessitating a long extension on the high-speed grinding spindle. Vibration was eliminated only by carefully watching all conditions closely.

Obviously, work of this large size stretches the capacity of this machine to the limit and cannot, at present, be recommended with certainty. It is hoped that, in the near future, means may be provided that holes of this size and depth, although requiring a fairly large wheel on an extension fully as long as the vertical slide travel, may be ground efficiently and with directness.

Although admittedly performed inefficiently in the Jig Grinder, the question arises, "how else could it be done?" It could, of course, have been left soft, bored to size in a large Jig Borer. In fact, similar

molds were so made. This is a high-production job, however, and cavity inserts require frequent replacement. Scoring, shearing, and wear increase the sizes of the holes rapidly; new inserts do not fit tightly. In addition, wear on the pin holes is extremely destructive. It was decided, therefore, to harden the piece and grind it for longer life.

As an alternative to Jig Grinding, it could have been ground in a conventional internal grinder. Inasmuch as accurate *location* is required, this would be a tedious job and extremely cumbersome. Since the piece weighs nearly 200 pounds, it would require very careful counterbalancing in a machine capable of swinging at least 36″ on the faceplate, seldom found in a toolroom. It would be necessary to rotate it so slowly as to be impracticable.

For these reasons, Jig Grinding was selected. In spite of the admitted inefficiency in the grinding, the accurate performance and long life of the mold have more than justified the decision.

Grinding of Gages — The Jig Grinder is of enormous value in the fabrication of gages or master plates, Figs. 270 and 271. Outmoded conventional practice is to leave the bodies of such gages soft, Jig Bore them, and press in hardened bushings. This compromise, with its attendant shearing and excessive wear, is no longer necessary.

Jig Grinding permits the use of hardened bodies, which is a great advantage, even

Fig. 270 — While approaching size, hole is checked with Leaf Taper Gage. Workpiece is mounted high enough to permit measuring bottom, as well as top, of hole.

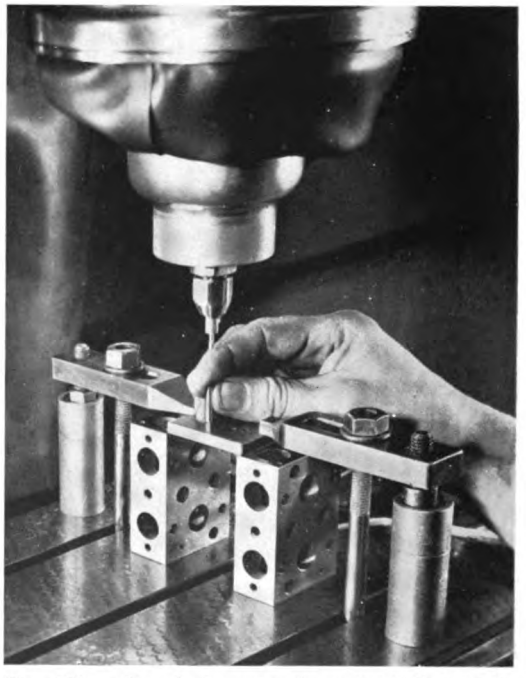


Fig. 271 — Round plug gage is most satisfactory for final sizing, but not suitable for approaching size since plug cannot be inserted until size is reached.

though hardened bushings may be used to take the wear. It is extremely difficult to press bushings into soft bodies without shearing or distortion. Shearing hardened bodies is practically impossible. .001″ or .0015″ press fit is needed to hold bushings tightly in soft bodies, although held securely in hardened plates with as little as .0002″ or .0003″. This is a big factor in maintaining high accuracy, since excessive press fit distorts the entire plate.

In cases where holes are too close together to bush, hardening of the body sometimes saves the making of an extra gage by taking the wear directly in the body.

The gage maker should cooperate with the Jig Grinder operator to the fullest extent, and vice-versa. Here are a few suggestions:

Leave extra thickness on the gage body, subsequently to be ground off to eliminate bellmouth.

Leave least amount to grind in the holes most difficult to grind, usually the smallest. The Jig Grinder operator can orient the piece from these holes.

Lap the face of the gage for mounting on parallels. This eliminates distortion from clamping, also prevents scratching and burrs.

Gagemaker should not expect Jig Grinder to grind holes up to size. Lapping a few tenths improves the surface of the hole, does not affect its location, but lengthens its life enormously. Bushings may be held with less interference for press fit.

For this reason, the gagemaker should furnish the Jig Grinder operator a plug .0004″ undersize for final checking of each hole, Fig. 271.

Note that the gage is set on high parallels, for checking the bottom, as well as the top, of the holes, Fig. 270. Leaf taper gages are excellent for checking the holes as they approach size. Final checking both top and bottom of holes is best done with a plug gage, however, Fig. 271.

Note that the special straps, for special purposes such as this, permit holding small plates without interfering with grinding wheel chuck.

The reader will also notice that this job is mounted near one end of the table. This is for reasons previously mentioned. Locating work in various places promotes more uniform wear on all parts of the table and ways. It also leaves part of the table clear, to take care of some emergency job that may come along, without disturbing the setting of this one.

When picking up and grinding a previously ground hole, make contact very slowly, watching carefully that the new grinding action hits the average of the previous grinding.

The plate in Figs. 270 and 271 contains 20 holes, ranging in size from .030″ to .201″ diameter. Total Jig Grinding time: 15 hours. .005″ to .008″ stock left for grinding.

Construction Holes — Construction holes are an exceedingly handy device. Sometimes, in fact, they are a practical necessity, as in determining positions of angularly-located holes, Figs. 272 to 275.

The problem: to locate a pin hole, Fig. 272, at 20° from the center line of a gage body, starting at a point in the plane of the bottom of the circular recess and .1808″ from the center line. A construction hole is bored and ground on the center line, at some known distance *a* from the bottom of the recess. With the piece on the Micro-Sine Plate, Fig. 273, the construction hole is picked up. Location of the desired hole is attained by moving through distance x, as shown in the sketch.

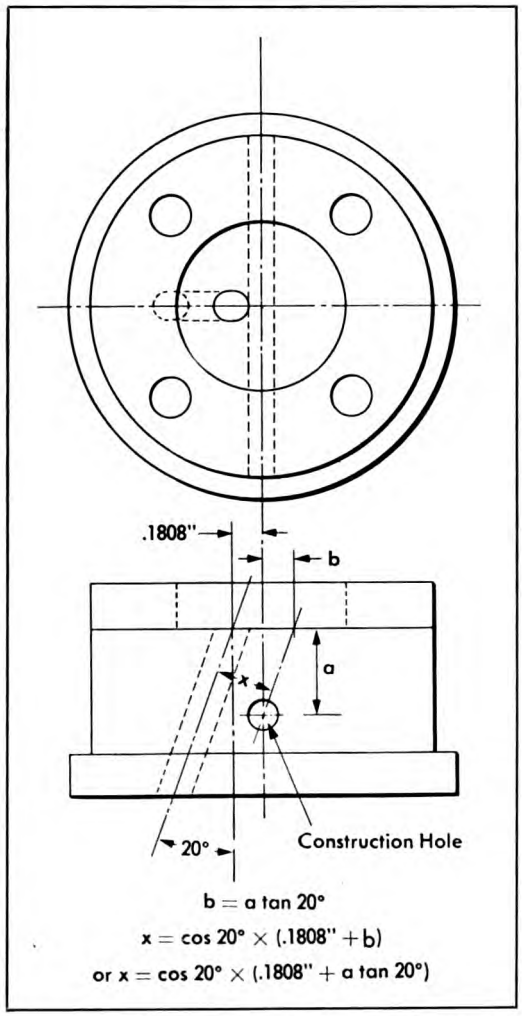


Fig. 272 — Dimensional details of gage body, showing construction hole.

The construction hole must be bored and ground from both sides, due to its great length. It is necessary, also, of course, to pick up both ends of the construction hole with pins, Fig. 273.

To pick up the circular recess, a snug-fitting plug is inserted and indicated, Fig. 274. Due to the fact that it stands on an angle, this pickup is effective in only one direction. Moreover, the indicator cannot be rotated all the way around, but must be withdrawn after checking each side before proceeding to the other.

This introduces the problem of ascertaining that the indicator is set at the same height when checking both sides. It is not necessary to set the vertical stop for this. Watch the indicator and move it up and down as it is rotated back and forth on the side of the plug. The highest reading vertically and the lowest reading angularly represents the point to be found. Obviously, there is a similar point on the other side. Similar indicator readings on both sides show the spindle to be central.

Due to the complexity of setup and great accuracy required, the time for grinding this one hole, Fig. 275, is con-

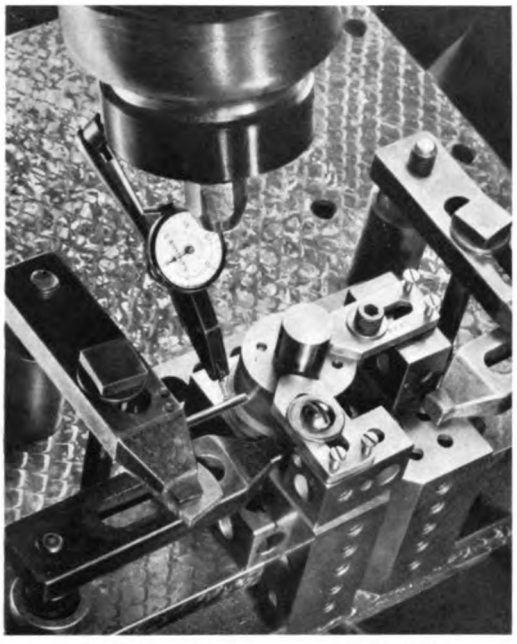


Fig. 273 — Picking up construction hole.

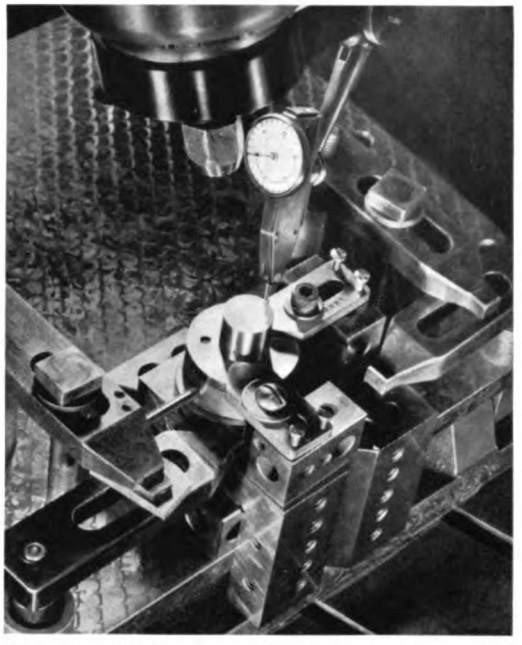
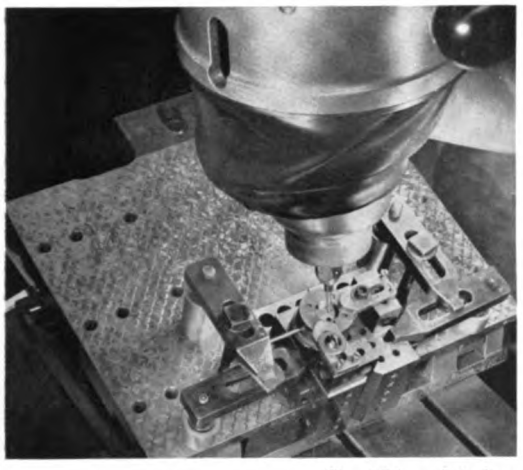


Fig. 274 — Picking up circular recess with dummy plug.



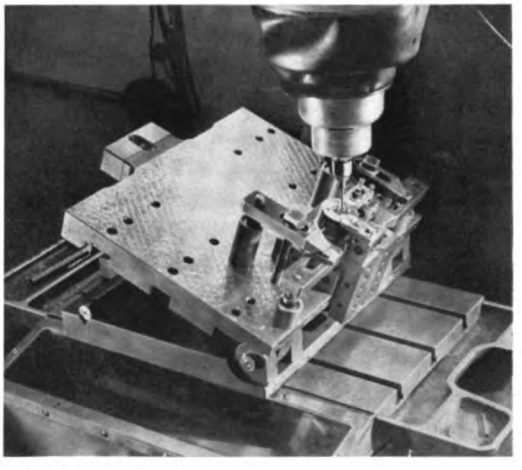


Fig. 275 — Grinding angular hole, two views.

siderably more than average. Setup and grinding to .0004″ undersize to allow for lapping consumed 4 hours, on the basis of one piece at a time.

Construction holes are sometimes employed as a matter of convenience in orienting parts to be fitted together. Each section of the die, Fig. 276, for example, was Jig Bored before hardening. After hardening, each piece must be ground all over to insure a close fit and accurate orientation with the other parts.

Along with the other Jig Boring, two construction holes (arrows) were Jig

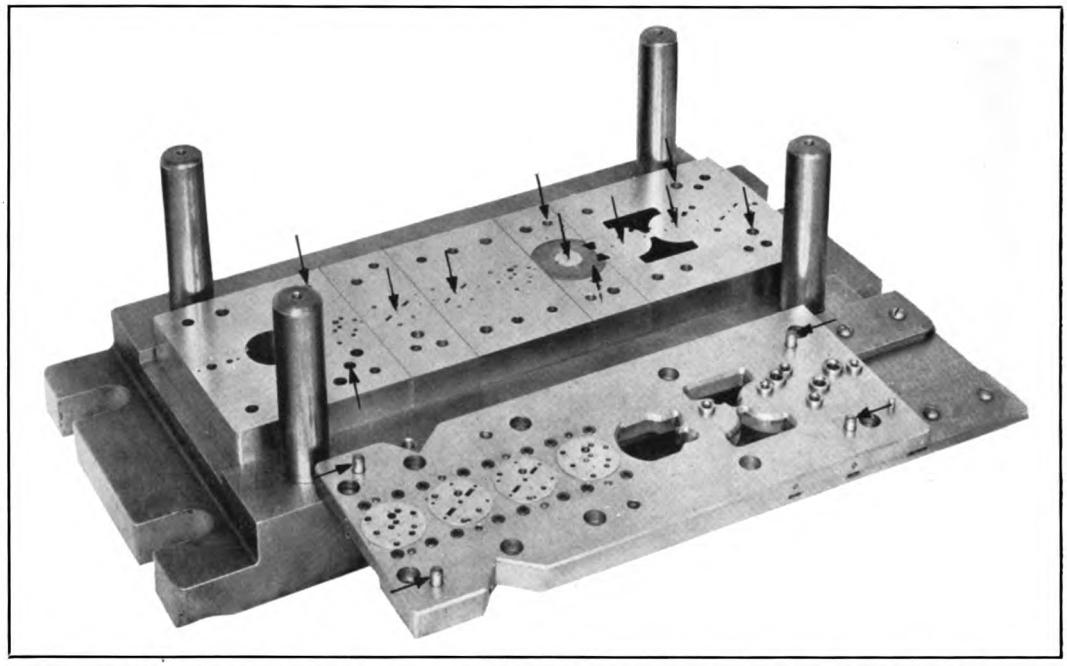


Fig. 276 — Construction holes are helpful in fitting together die parts and subsequent Jig Grinding.

Bored into each section. After hardening, the distances between these holes is no longer standard. However, they hold a good *average* relationship to the filing, other Jig Boring, or other operations on each piece. They are employed as references for surface grinding and assembly. Before Jig Grinding, the construction holes in each section of the assembled die are checked, to ensure accurate relationship and subsequent cleaning up of all the Jig Bored holes. They also provide a reference against which to check whatever portions of the die must be filed up before hardening, and, therefore, cannot subsequently be altered by grinding.

The die in Fig. 277 pierces tapered slots in the piece parts (upper left). The construction holes, in this case, are employed as references for grinding the die inserts to size and shape.

Correcting Dowel and Dutchman Holes — For constructional purposes, it is sometimes necessary to Jig Bore dowel holes, or Dutchman holes, in two mating parts, then to re-align them after hardening. It is not always expeditious to re-grind them to locational dimensions, especially in the case of Dutchman holes, or if too little stock remains in a dowel hole to clean it to a standard size.

To correct the location of a hole, its diameter must be increased by twice the distance its center is moved, Fig. 250. Some operators are also confused by a similar phenomenon in connection with an error shown by indicating. When the machine is set to read an error in eccentricity

on the indicator, the indicator reads *twice* the locational error, but the *true* amount by which the diameter must be increased to correct it.

It may be more desirable in the case of two mating dowel holes, Fig. 278, to increase them only to the next nominal size, by grinding to their average position, than to increase them both enough to attain the present location of either. The problem is, then, how much the workpieces should be moved from the location of either hole to attain the average location of both.

Assume both holes to be the same size, and of some measured diameter D. Make a plug which will just go through the juncture of the holes. Call its measured diameter d.

Determine the present location of the top hole by indicating, and move toward the present location of the other by an amount of one-half the difference between the diameters of the hole and that of the plug, represented by the formula:

$$\text{distance moved} = \frac{D-d}{2}$$

Dutchman holes, Fig. 279, may be averaged by indicating the tops of the protruding inside corners, or by grinding by trial and error, grinding approximately equal amounts from the corners.

Correcting Holes in Hardened Pieces After Assembly — It is not always practicable to insist on strict interchangeability of all tool parts. Strict interchangeability sometimes requires too many high precision intermediate steps. A succession of holes in assembled parts are liable to

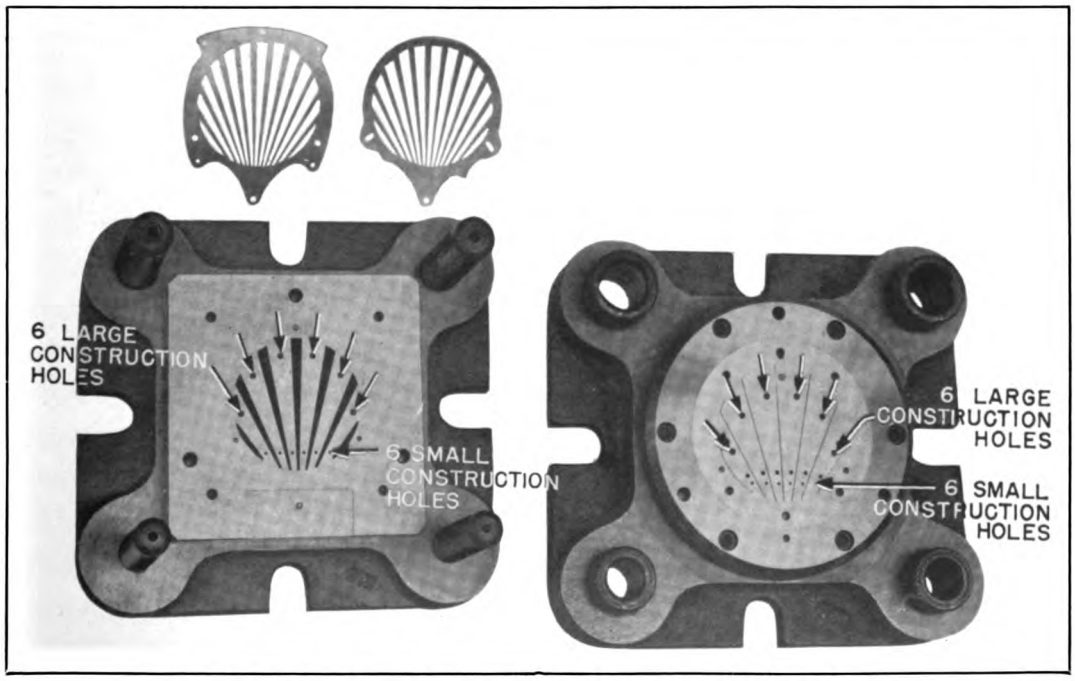


Fig. 277 — Extreme precision required here; material pierced is only .003" thick.

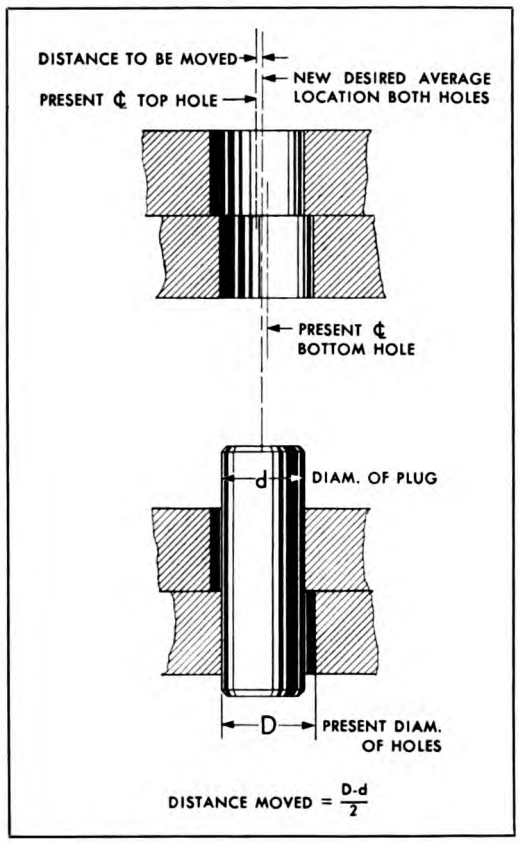


Fig. 278 — Formula for averaging location of two mating dowel holes.

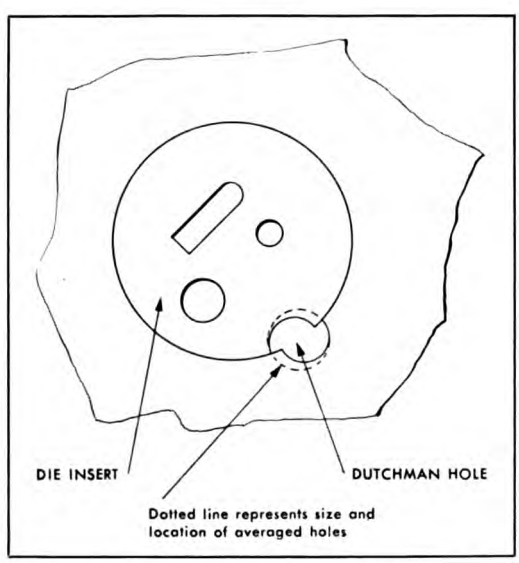


Fig. 279 — Protruding inside corners of Dutchman hole represent average location (dotted circle).

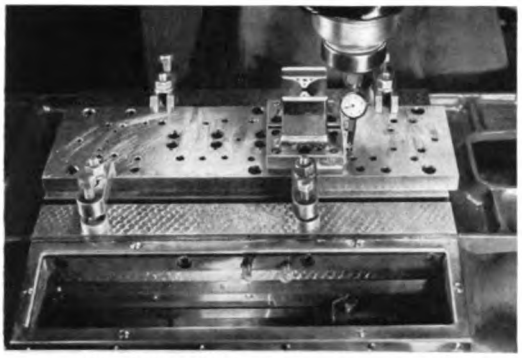
accumulate substantial errors. To avoid this, parts are sometimes assembled and Jig Ground in place. Parts so made are not strictly interchangeable, but are replaceable within reasonable cost. Figs. 280 to 282, all parts of the same die, represent examples of this.

Fig. 280 shows the picking up of Jig Bored holes in the punch plate, preparatory to Jig Grinding pilot holes in the gutting punches. Alignment of pilot holes is a matter of vital importance to the operation of multi-station progressive dies. Not only one hole but several should be picked up, and their positions averaged before grinding the pilot holes.

Fig. 281 shows a similar operation on the stripper of the same die. Pilot hole bushings are being picked up, preparatory to grinding the punch-guiding holes (see arrows) in the hardened stripper inserts.

The same relative operation is being performed in Fig. 282 on an insert in the die block itself. The irregular-shaped detents are in reality in inserts, filed, hardened, and pressed into the die block. The desired piercing hole (see arrow) is also in this insert, and is to be Jig Ground. Since it is necessary to maintain accurate relationship with other holes, the pilot holes are being used as references for the location of these piercing and shaving stations.

Contour Grinding — While the Jig Grinder was designed primarily for locational hole grinding, its versatility permits



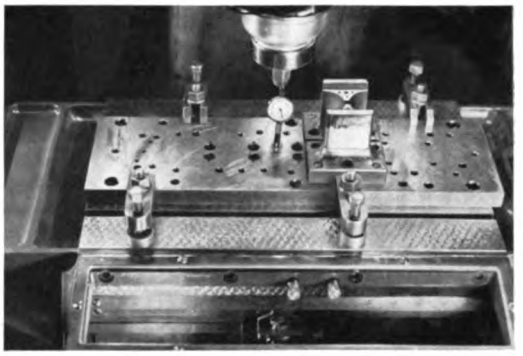


Fig. 280 — Picking up average of two holes preparatory to grinding pilot holes in gutting punches.

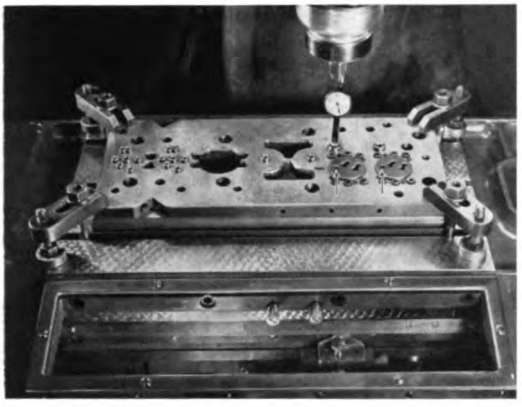


Fig. 281 — Picking up bushing preparatory to grinding punch-guiding holes in stripper insert.

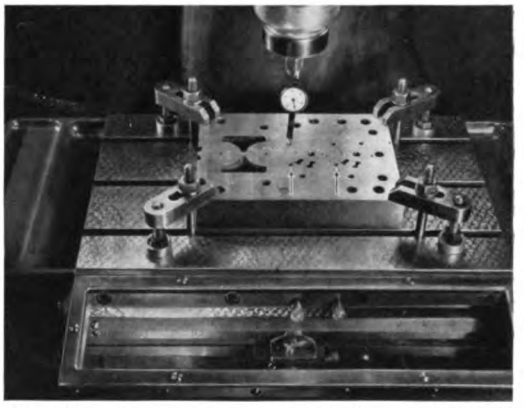


Fig. 282 — Same, preparatory to grinding piercing holes in die block.

its use for contour work under certain conditions. The header die and the compound die section, Fig. 283, are simple examples of this. Holes in these parts consist of radii joined by straight tangents. The radii at the ends are ground just as holes would be. When grinding the tangents, the part is oriented parallel to the desired tangent, and the machine rotated and traversed vertically, also just as in grinding the hole. In this manner, the wheel hits the work only during small periods of time, creating small radii, Fig. 286. This may seem crude and slow, but, considering the accuracy of the final product, it compares favorably with other methods.

The slot in the header die, Fig. 283 (left), is ¼″ wide, ¾″ long, and ground to a depth of ¾″, tapered for draft, or ejec-

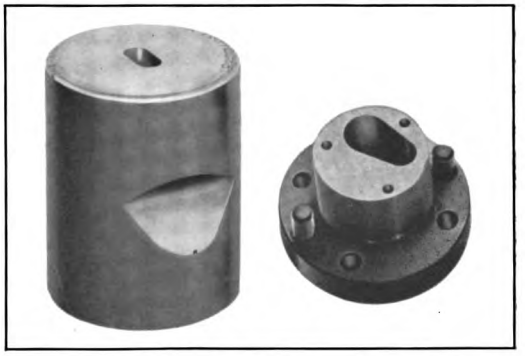


Fig. 283 — Header die (left), compound die section (right), may be contour-ground in the Jig Grinder.

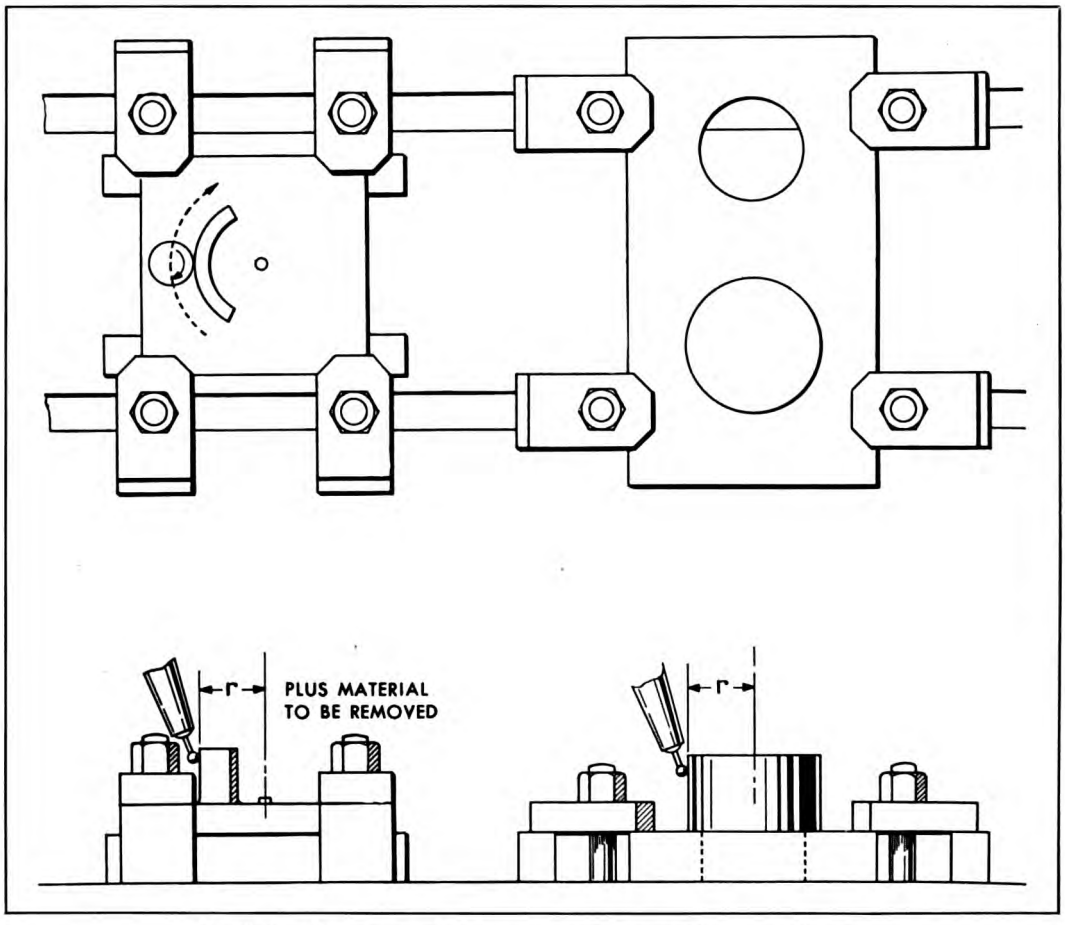


Fig. 284 — Ingenious method for measuring diameter of segment of circle.

tion, larger at the top. Grinding is accomplished in one hour per piece. The pear-shaped hole in Fig. 283 (right), is about ¾″ diameter at the large end, and ½″ diameter at the small end, and about 1¼″ overall length. It can be ground through ¾″ of thickness in two hours.

External, as well as internal, radii may be ground in the Jig Grinder, provided they are not too large. Fig. 284 represents a punch, whose cutting portion consists of a segment of a circle. Grinding is achieved, both on the internal and external radii, by rotating the main spindle and the grinding spindle in the usual manner.

One problem in connection with this type of job is determining the size of the radii ground. Since only a portion of the radius exists, there is nothing from which to measure the diameter. To achieve this, a dummy plate is made, containing a hole of the correct internal diameter and a plug of the correct external diameter. This plate is strapped to the table alongside the workpiece, and the locations of the hole and plug picked up. These may be quickly

related to the main spindle at any subsequent time by repeating these table settings.

To determine radii being ground: Set main spindle over hole or plug, bring indicator against surface, and note reading. Move to center of radius being ground, bring indicator against surface. Compare indicator readings. Amount of plus on indicator shows stock yet to be removed.

Contour grinding in the Jig Grinder has even proved practical for complex punch and die shapes, when the blank contour consists of definitely dimensioned radii and tangents.

The die sections, Fig. 285, represent an example of this. Each punch, or section of the die, is mounted to its correct position and angular orientation on a plate containing a small Jig Bored hole at each radius center. The plate is previously Jig Bored to rectangular coordinates and is moved about on the rotary table, plugging into each hole with a true plug in the rotary table center. Each radius is Jig Ground, following the planetary principle, and rotary table rotation, Fig. 286.

Since the workpiece is angularly oriented, the end points of the radii are determined by calculated rotary table settings. Small internal radii at ends are ground to position and size by table settings, as any hole would be ground.

The reader will notice a plate containing several holes, strapped to the rotary table. This is for the purpose of determining size

Fig. 285 — Complex die sections may be contour ground, providing they consist of radii and tangents. In this case, curvature is determined by rotation of rotary table.

of the radii as ground, as in Fig. 284. Sizes and coordinate settings of these holes being known, radii may be determined by comparison with indicator.

The Jig Grinder as a Production Machine — Jig Grinding of machine and tool parts in production permits taking full advantage of precise tolerance specifications, with resulting better alignment of mating parts, longer life, and smoother operation. It puts the final positioning and grinding of holes in hardened work on a true "machine shop practice" basis, and eliminates trick and makeshift setups.

In fact, production possibilities are fully as important for the Jig Grinder as for the Jig Borer. Soft parts may be drilled and reamed with jigs. Hardened pieces, on

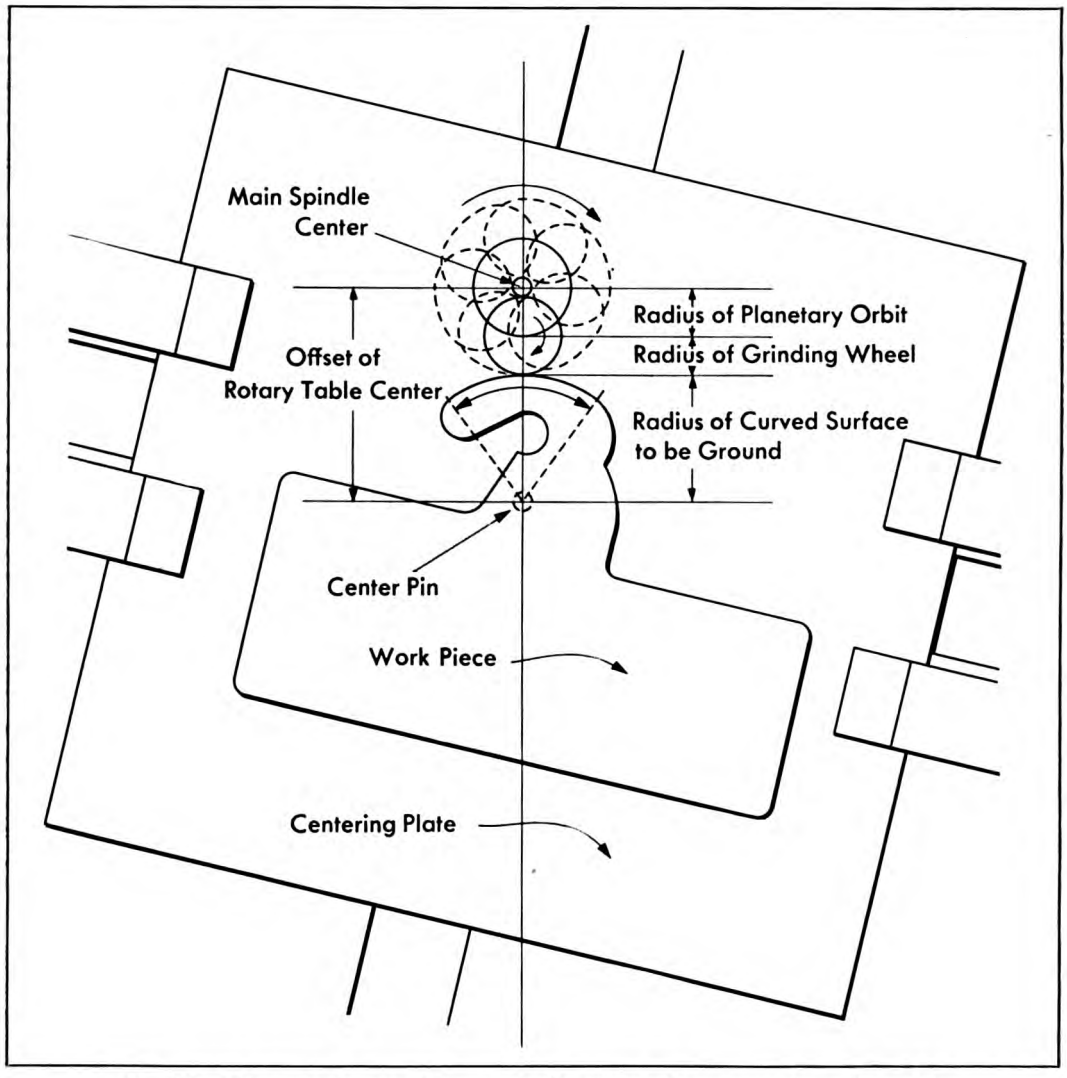


Fig. 286 — Schematic drawing of operation in Fig. 285. Surface generated actually consists of a succession of minute radii.

the other hand, cannot be reamed or drilled; they must be finished by *grinding*.

Figs. 287 to 289 show how the built-in accuracy of the Jig Grinder begets itself. The parts in Fig. 287 are actually parts of a Jig Grinder. The control spindle in Fig. 287 is recognizable in the fixture, Figs. 288, 289.

It is necessary to grind the two ¼″ holes in the ear-like projections at the large end of the piece, in line and at right angles to the axis. The center line of the fixture is indicated true with the main spindle. Parts are placed between centers, and one hole ground at a time. Indexing through 180°, on *dead centers*, assures the best possible alignment and perpendicularity of holes. .0003″ to .0004″ are left in each hole for subsequent line lapping.

Time required: ½ hour per piece.

Tool parts are also sometimes required in large quantities, for multiple drilling and the like. Forty flanged drill guides, Fig. 290, were required. A temporary fixture, Jig Bored, fitted with locating pins and mounted on the Jig Grinder table, serves to locate the inserts one after another, production fashion.

The locating pins are picked up by their proper coordinates. Thereafter the location of the three holes to be ground are determined by moving to their correct coordinates. Two holes, ¼″ and $\frac{9}{32}$″ diameter, respectively, were ground, ⅝″ deep. Time per piece: one hour.

That the scope of the applications of the Jig Grinder is by no means limited to tool and die work or small-lot production was emphasized during World War II when eighteen of them were installed in the production lines of a well-known automotive plant on a *mass-production* job. The grinding problems involved in this plant were in connection with the manufacture of the gears, Fig. 291, for vitally needed aircraft engines.

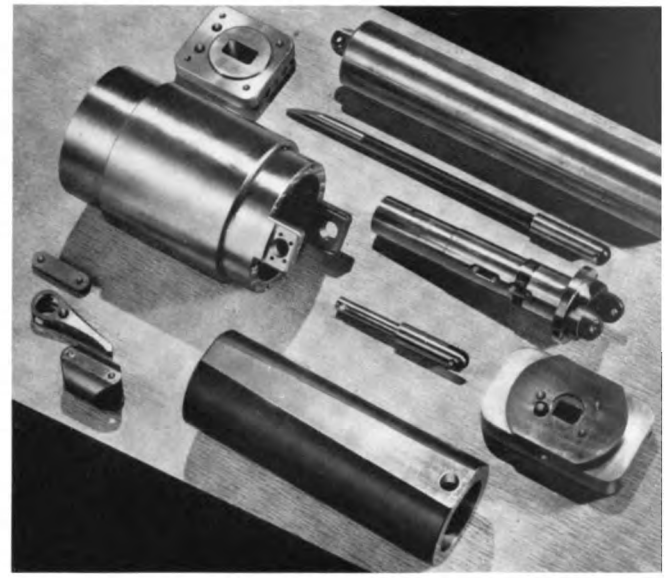
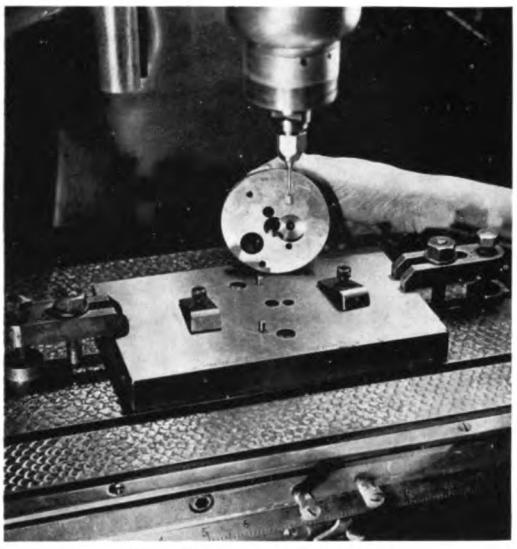


Fig. 287 — Parts of Jig Grinder, all Jig Ground.

Only two modifications were required to adapt the Jig Grinder to this production job: (1) A special gear ratio in the power feed to permit automatic plunge grinding, previously described, Figs. 234, 250, and (2) a simple stationary precision indexing fixture for each gear, incorporating automatic hole-sizing through wheel dressing.

Fig. 288 — Aligning indexing fixture preparatory to grinding.

Fig. 289 — Jig Grinding assures smooth operation and long life of machine parts.



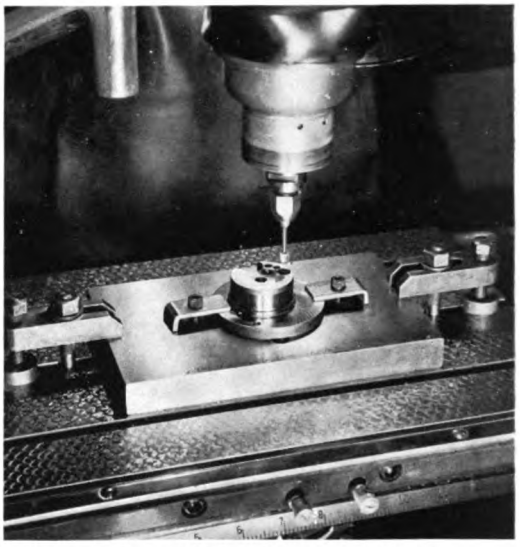


Fig. 290 — Tool parts required in large quantities may be set on fixture (left) and jig ground (right).

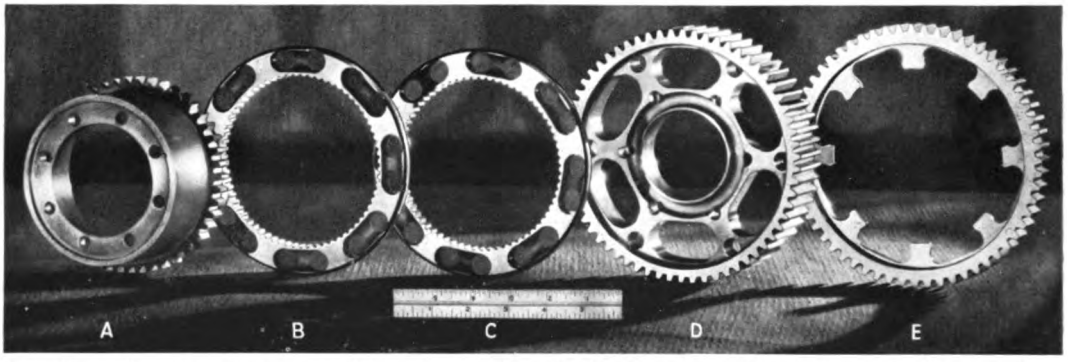


Fig. 291 — Aircraft engine accessory drive gears, on which Jig Grinder performs the following production operations:

On B, C, D, and E, semi-circular ends of oblong cavities or spaces between lugs are ground, diameters and locations being held to ± .0005".

On B and C, ends of pockets are ground to shoulder near bottom, to depth ± .0005". In gear A, eight holes are ground to size and location ± .0003".

Most of the features required to adapt the standard Jig Grinder to this mass-production job are incorporated in the work-holding fixtures, Figs. 292 to 296. The main considerations in the design of these were high accuracy and convenience of setup and operation. The basic design features of the fixtures consist of a rotating hardened plate, Jig Ground and bushed, which is the indexing control, and a spring plunger, which snaps into the bushings, thus positively determining angular location.

Exact gear-locating in the machine is of great importance, because of the close tie-up between the grinding and all previous operations. In addition to centralizing by means of a close-fitting plug, or pocket, as illustrated, each gear must be oriented to its correct angular relationship. For

this purpose, a plug held in by spring pressure is employed. The "business end" of the plug corresponds to a rack tooth or to two rack teeth, and locates on the pitch diameter of the gear. In some cases, this locator fits between two of the gear teeth, in others it straddles a single tooth. One tooth of each gear is marked. This is the reference point for setting up every operation in the processing of the gear. Thus the angular position of the gear in the fixture is determined and uniform grinding allowance is maintained in all radii and holes.

Each fixture is equipped with an adjustable wheel-dressing diamond, Fig. 292. The position of the diamond is such that a pass of the wheel over the diamond dresses it to an exact predetermined diameter, so that the radius is automatically ground to size. The diamond is pre-set to its calculated position by means of a setting block located in a hole in the top of the diamond-holding arm. When it is advanced to the point where it just touches the pin in the block, its position is correct. While this must be rechecked occasionally, gaging time is cut to the minimum.

In view of the fact that this machine does have planetary motion, the question may be raised as to how the angular position of the main spindle is maintained during the dressing so that the wheel is dressed to the correct size. The answer is an interesting part of this discussion. The main spindle is, as a matter of fact,

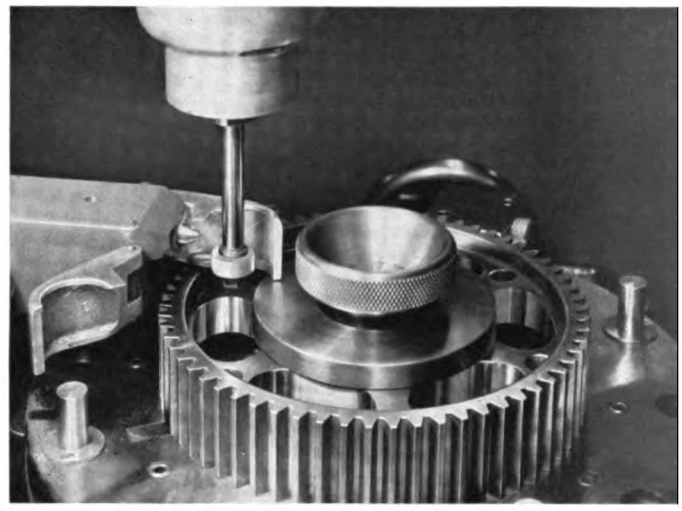


Fig. 292 — Gear D, Fig. 291. Revolving and traversing at operating rate, wheel is dressed by pre-set diamond, then continues on to grind curved face of spoke to correct radius and location. Hole in top of arm locates diamond-setting block, not shown.

allowed to rotate during the dressing. It would seem at first that this would tend to promote irregular, bumpy dressing. Actually, however, the steadiness of the main spindle and the high relative speed of rotation of the wheel spindle with respect to the main spindle and to its down travel, prevent this.

Observation of the wheel and of the work produced by it show this method to be highly effective and accurate. This is true because the wheel is dressed under actual operating conditions. Accordingly, the machine is not stopped from the time the gear is loaded until it is unclamped and removed from the fixture.

Each fixture is equipped with clamping devices which are foolproof, so that the hole to be ground is entirely clear, with no danger that the operator will hit any

part of the clamp with the grinding wheel. In addition, as will be observed in Fig. 293, pick-out slots and a lifter are provided, just in case a gear should fit its locator snugly, or in case a particle of dirt should make removal difficult.

Although these Jig Grinders were equipped with the usual neoprene aprons, additional facilities were included to remove as much as possible of the dirt at its source.

It will be noted in Fig. 294 that, integral with the diamond wheel dressers, there are air inductors designed to draw off the particles dressed from the wheel or ground from the work. This flow of air also acts as a coolant, maintaining proper work temperature and minimizing clogging or glazing of the wheel. The fixtures themselves, including rotating mechanism, gear-locating devices and plungers, are sealed against dirt.

Although the Jig Grinder has accurate measuring devices for both directions of the table travel, it was decided to use only one for this job. There are two reasons for this, the first being to facilitate setting up. Angular positions of the indexing stations are so arranged that, once the center of the fixture is located with respect to the main spindle, it merely is necessary to move the table forward a precalculated amount (stamped on each fixture). Locating lugs on all fixtures, held against the table when clamping them in place, assures correct angular relationship. Once set, the table position need not be changed as long as it is set up for any particular gear.

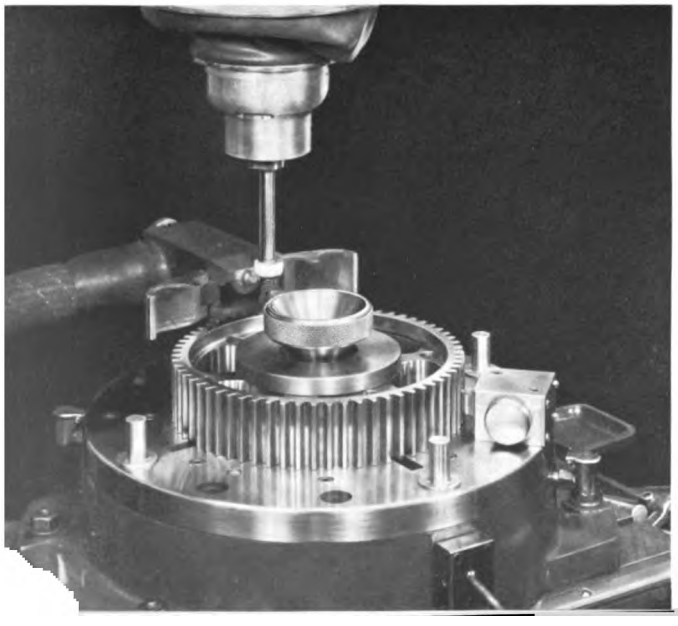
The second reason is to prevent interference with diamond dressing. Since the diamond holder is attached to the fixture, any movement of the table, carrying the fixture with it, would move the diamond into an incorrect dressing position.

In addition to their quick setup features, the fixtures promote simplicity in the work cycle described in the following paragraphs. Except for variations in hole sizes and shoulder grinding, the work cycle is almost the same for all gears.

Loading and clamping procedure is as follows: The gear is dropped over the central locating plug or into a pocket. Next, the angular locating plug is inserted between the proper gear teeth. Clamps are now dropped in place and tightened, as indicated in Fig. 293.

Then comes wheel dressing and auto-

Fig. 293 — Another view of gear D, Fig. 291, showing rack tooth locating plug for external teeth. When indexing table, handle at right front releases spring-actuated plunger. Slots in table permit insertion of lifter bar in case work sticks on locators.



matic sizing. Obviously the wheel must be dressed more frequently for some of the gears than for others. For instance, gear D, Fig. 291, with its thick web, requires wheel dressing after every two passes. All the holes in gear A, on the other hand, are ground with one dressing of the wheel for roughing and another dressing for finishing.

The fixture for gear A is equipped with a turret, mounting two diamonds, one for roughing and one for finishing, as shown in Fig. 296. The holes are all roughed alike to .001″ undersize, the wheel redressed, and the holes finish-ground.

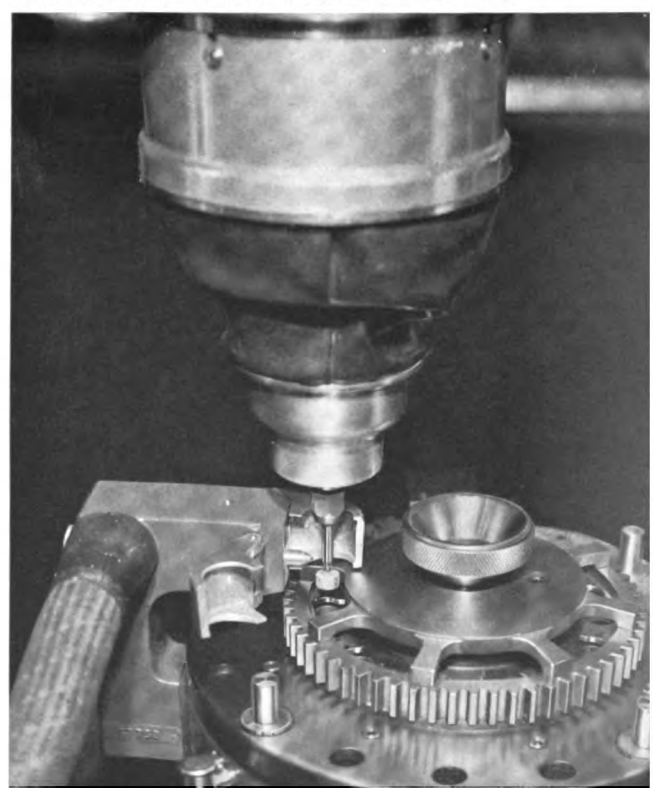
Dressing is done during the time the operator is indexing the fixture between cuts; therefore, it adds no appreciable amount of time to the work cycle. The wheel is brought high enough by means of the handwheel to start above the diamond, in order to assure complete dressing. Then it is allowed to feed downward across the diamond. Thence it passes down through the work in a single stroke. It is unnecessary to stop the machine during the work cycle either for indexing, wheel-dressing, or gaging.

One pass of the grinding wheel finishes each hole or radius in most cases. Removal of stock and required finish are achieved by "plunge grinding", in a single operation, except for gear A. In plunging into the work in this manner, both the main spindle and the wheel spindle rotate. The wheel is fed into the work slowly. For this reason, the power feed gears in these particular machines have been altered to give the necessary slow rate of traverse.

The gage for checking hole position and size consists of a pair of go and no-go plugs mounted the correct distance apart in a holder. This effectively and simultaneously checks the positions and sizes of the radii or holes ground. It is unnecessary to stop the machine for gaging. Each pocket or hole can be checked during the time the succeeding pocket is being ground. Any possible spoilage, therefore, is detected immediately, and the part eliminated before any further work is done on it.

Bottoming the pockets in gears C and D to the correct depth is achieved through the use of the positive depth stop, Fig. 217.

Fig. 294 — Sides of internal lugs, gear E, Fig. 291, are ground to size and location. Hollow arm holding diamond serves as vacuum nozzle for removal of abrasive dust and metallic particles. Airflow also cools wheel and work. Guard doors around diamond are closed when operating.



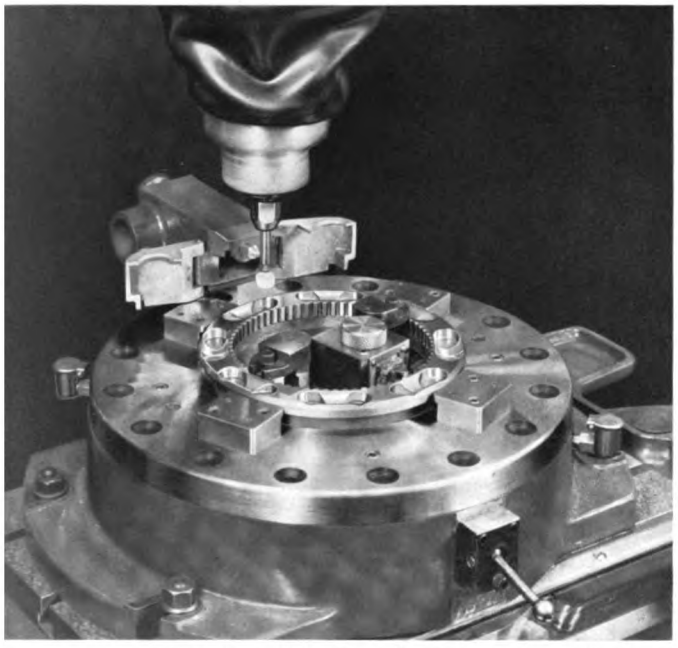
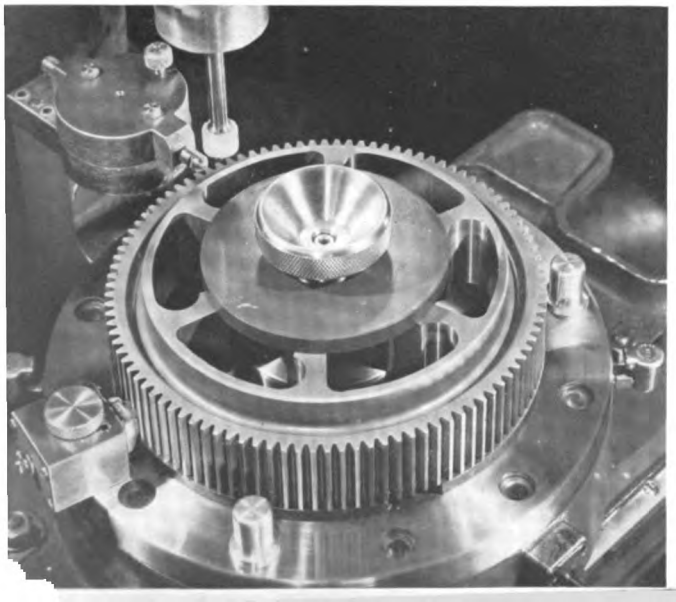


Fig. 295 — Grinding ends of pockets, gears B and C in Fig. 291. Fixture locates external diameter in pocket formed by four locating blocks. Internal rack tooth plug provides angular location.

Compensation for wheel wear is achieved by backing off the limiting screw.

To facilitate unloading, the diamond dresser, in each case, is set at sufficient height to give necessary clearance. After removal of the clamp, the gear simply is lifted off, or, if necessary, the lifter is employed in the pickout slots, Fig. 293.

Fig. 296 — Cup-shaped gear A, Fig. 291, located by internal plug and external rack tooth. Wheel makes two passes in each of eight holes, .001" being left for final pass. Indexing turret at rear holds two dressing diamonds, one for roughing, the other for finishing.



Time required for the operations described varies with the types of gears. The longest time, that for gear D, is 30 minutes. The shortest is for gear E, 15 minutes. This in each case is "floor-to-floor" time.

The principal advantages of the Jig Grinder on this gear job or on similar work are derived from its vertical construction and planetary action. Among these advantages are accuracy, speed, and operating convenience. Requirements for accuracy involve two considerations, location and sizing.

Because it uses stationary fixtures, the Jig Grinder eliminates the necessity for any compensation for centrifugal forces, either in the location of the fixtures, the gears in the fixtures, or in the mechanism of the fixture itself. Location is achieved with Jig Borer precision.

No trouble is encountered with automatic sizing through diamond dressing, because the diamond is held rigidly in close proximity to the work, thus maintaining a high degree of accuracy.

The planetary mechanism, with its light, precision-built parts, safely can be rotated at the high speed necessary for effective grinding.

Inasmuch as the gears are ground by women operators, bending, lifting, and

other physical efforts must be minimized. Operators work conveniently in comfortable sitting position. Loading, indexing, and operation of all machine controls require very little effort. The stationary fixture permits easy observation and gaging without stopping the machine.

On any grinding job, use of correct wheels is a potent factor in attaining operating efficiency. Selection of the proper wheel deserves study and experimentation.

On this gear job, the wheel selected for each operation represents a compromise of several controlling factors. Since the work involved on some of the gears differs from that on others, the same grits and grades are not used in all cases. Some wheels are mounted points, others are arbor-mounted.

Some of the major factors determining final wheel selection may be of interest. Use of coolants on production grinding interferes with gaging. It was decided, therefore, to select wheels which can operate dry. Softer grades of wheels are employed than otherwise would be the case. These insure that sharp, free-cutting particles are constantly exposed.

This correct wheel "breakdown" also is necessary in order to generate automatically a radius at the shoulders near the bottom of the pockets in gears B and C. Plunge grinding tends to produce this radius on the corner of the wheel. Therefore, a wheel of proper hardness automatically generates the desired radius.

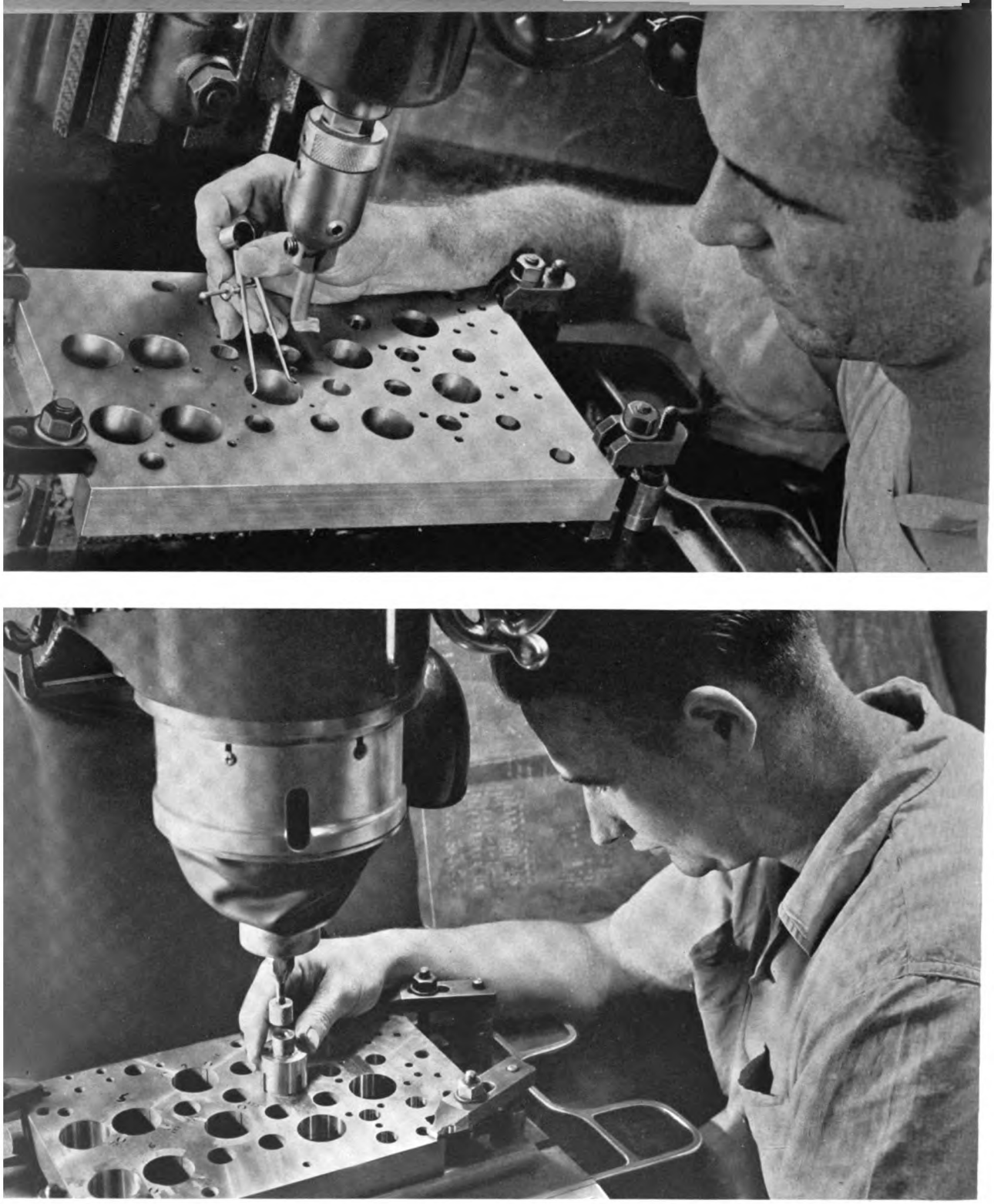


Fig. 297 — Jig Boring and Jig Grinding quadruple die, Fig. 304. Manufacture of tools on interchangeable parts-and-assembly basis promotes phenomenal delivery of dies to pressroom.

Chapter VII

NOW — INTERCHANGEABILITY IN TOOLMAKING

THE TOOLMAKING industry, first to promote interchangeability in manufactured goods has, paradoxically, been the least progressive in introducing the principle into its own operations. Interchangeability is now so firmly intrenched that its acceptance is mandatory to any progressive industry. Why not toolmaking? The toolmaker's conception of his work has always been a one-at-a-time proposition, made *to fit* instead of *to figures*. He has apparently overlooked the fact that tool parts, if made strictly to dimensions, will assemble and operate just as well as any other manufactured device.

One of the major parts of the toolmaker's job has always been hole locating, and it is amazing that, although this problem has irritated him for so many years, no real engineered solution has been developed until recent times, the Jig Borer in 1917, and the Jig Grinder as recently as 1940. Clearly, the toolmaker should heed the Biblical edict, "Physician, heal *thyself*".

The Jig Borer, a partial remedy, is fairly well known by toolmakers, having established itself during the past two decades. The Jig Grinder, of more recent origin, is less known. Still less known is the value of the two as *partners*, working together.

Complete Hole Location Service Expands Toolmaker's Capacity — Since the problem of locating holes is one of the toolmaker's major headaches, his full productive capacity cannot be employed unless there is available to him a complete, well-rounded hole location service. This service must include facilities for both the boring and grinding of holes. Neither the Jig Borer, nor the Jig Grinder, is a complete service by itself.

A partnership is required, Fig. 298:

1. The Jig Borer, to do the finish-boring in parts left soft, and to rough-bore the holes preparatory to grinding.

2. The Jig Grinder, the engineered solution to the problem of correcting holes in hardened parts by grinding.

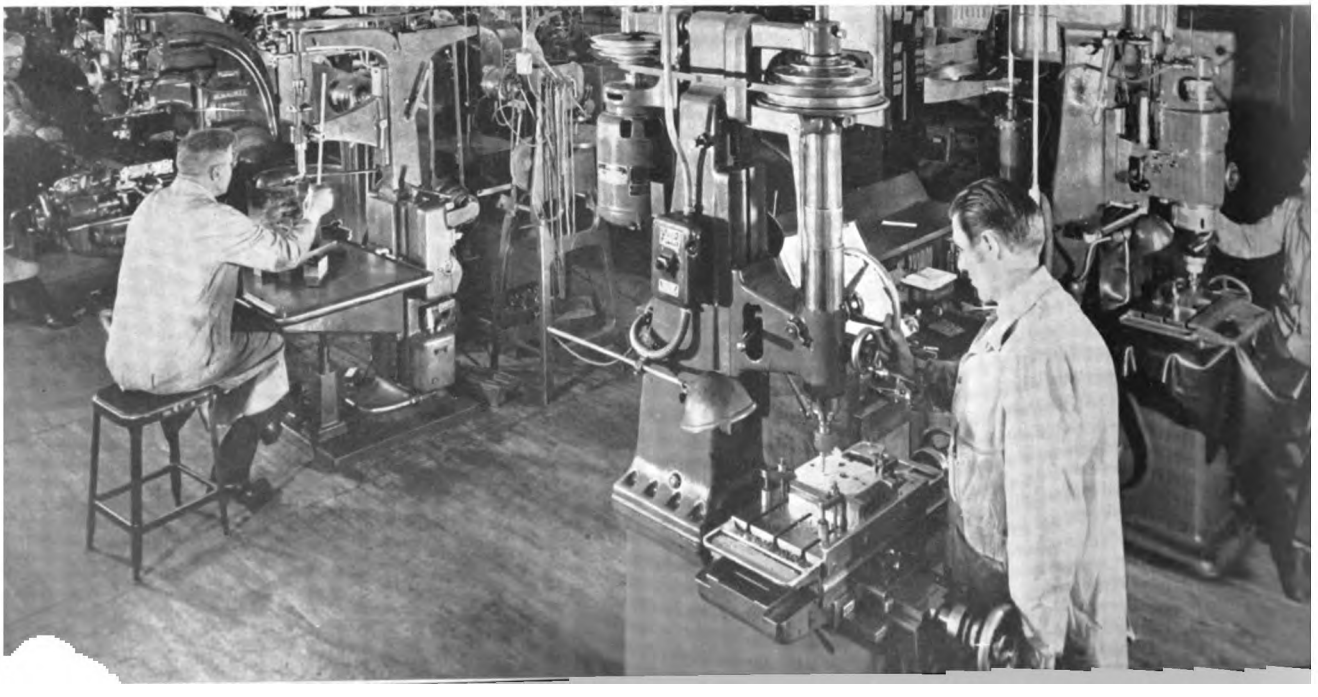
These machines should not be considered independently, each by itself, as pieces of equipment to aid the toolmaker, or merely as a solution to part of his problem. They are more than this. They are a means of projecting him into wider avenues of activity, of expanding the scope of his talents into more important phases of his work, such as advice in design and engineering, supervision of specialists, and assembly. It is in these fields that the toolmaker's experience and skill find their greatest usefulness. Tying him down to the drudgery of boring and grinding holes by obsolete methods is a waste of at least half of his potentialities.

In addition to serving the toolmaker, each machine complements and adds to the capacity of the other. Modern precision toolmaking practice demands their recognition as a team, operated by trained specialists, to relieve the toolmaker of the entire hole-locating job. Tools, like mass-produced items, can now be made on the basis of interchangeable parts and assembly, assuring the highest possible accuracy and economy.

So much for generalities. Superficial stories of our progress in mechanical refinements are so glibly repeated that they have become trite. We believe the reader's interest is more specific — he wants to see for himself, in detail, the advantages of modern practices, how they inevitably crowd out old, tedious methods, and how they predict future trends.

Most of the advantages of the Jig Borer-Jig Grinder partnership stem from their better accuracy and speed, and the great convenience with which these are achieved. These encourage the toolmaker's thinking

Fig. 298 — Specialization of equipment in modern toolroom. Lathes and milling machines are no longer employed as hole locating devices. The capacity of these machines is now available for work for which they were intended. Hole location problems are left to the Jig Borer and Jig Grinder (both at right).



along more direct, accurate lines, with resultant advantages in many obscure and unsuspected directions.

The ultimate desired result is, of course, lower cost to the consumer. Its steps are devious and complicated, with overlapping advantages. In order to understand these advantages in relation to one another, a chart, Fig. 299, will enable the reader to prepare himself for a thorough point-by-point discussion. This chart is intended to correlate the various advantages of the Jig Borer-Jig Grinder partnership in the reader's mind and to trace, in logical sequence, how each progressively promotes the next. Occasional reference to this chart will help the reader follow the detailed discussion.

The Jig Borer-Jig Grinder Partnership — A Complete Hole Location Service — Before discussing the various advantages of this partnership, it is well to define and describe it and show how both machines complement each other. As previously mentioned, the toolmaker requires a complete, well-rounded hole location service.

Both hard and soft materials, sometimes mating parts of the same tool, must be finished. Obviously, therefore, both the Jig Borer and Jig Grinder are essential. Part of the work ordinarily done by either machine can be performed by the other, but not without serious impairment of efficiency.

For example, the reader might question why it is necessary to employ the Jig Borer on parts which are eventually to be Jig Ground, pointing out that, inasmuch as the holes will be ground anyway, accuracy before hardening is non-essential. The fallacy of this reasoning lies in the fact that the Grinder operates at a disadvantage when excessive amounts are left for grinding. It is necessary, of course, to leave enough to grind in each hole to clean it up. To avoid excessive grinding allowances, the hole must be reasonably accurate before grinding. To locate holes in these cases accurately enough, layouts or buttons will be necessary, making extra work which could be saved if the Jig Borer were employed. Since ultimate accuracy is not required, this work can be performed very rapidly in the Jig Borer.

As another example, the reader might point out that it is possible to perform the Jig Grinding operations by employing the Jig Borer for establishing location, and then swinging the part up in a lathe or internal grinder. This, in fact, is common practice. The usual procedure is to insert a brass or steel plug into each hole and bore it in the Jig Borer, then use this hole as an indicating surface when truing the part up on the lathe or internal grinder for grinding, pages 153 to 157. The position of the ground hole must be carefully checked after grinding. The tediousness and inaccuracies resulting from this procedure are well known to every toolmaker and, of

JIG BORER-JIG GRINDER PARTNERSHIP: A COMPLETE HOLE LOCATION SERVICE

Jig Borer finish-bores annealed tool parts, bores preparatory to grinding.

Jig Grinder corrects locations of holes in hardened parts by grinding.

↓

Both use same coordinate location principle.
Each machine increases capacity of other.
Setting up and inspection tools interchangeable between machines:
Rotary table, micro-sine plate, bolts, straps, indicator, edge finder, microscope.
Each machine should be so tooled up as to derive greatest use from each other.

↓

Great convenience in attaining accuracy and speed.
Each machine its own inspector — Quick, certain inspection for hole location.

↓ ↓

Directness and accuracy, instead of indirect compromises. Selection of proper materials for wear resistance. Hardening gage and jig bodies. Tightening of tolerances. Elimination of transfer methods.

By-product:
Increased inspection capacity.

↓

↓ ↓

Happier, more productive toolmakers. Release from hole location drudgery permits wider scope for talents. Doesn't get hounded by "the boss".

Happier, more eager apprentices. Directness of advice in approaching hole location problem. Less discouragement, apprentice learns faster, covers more ground.

↓

Interchangeability in toolmaking, as in consumer items.

Lower tool cost. Saving of overall hours, parts made concurrently instead of progressively, many men on job at same time. Greater accuracy, less inspection and correction.

Greater value of tools as investment. Speeding up of tooling job, quicker delivery to production. Quicker setup, less tinkering, longer life.

↓ ↓

Increased toolroom capacity. Space and machine hours saved.

Increased manufacturing capacity, less spoilage, less "down time".

↓

Lower cost, better accuracy of piece parts.

↓

Lower cost, better quality of manufactured item.
Better appearance — Better operation — Longer life.

Fig. 299

course, are the reasons for the building of the Jig Grinder.

Not only is each machine essential for its own type of work, but each actually increases the capacity of the other. The Jig Borer, for instance, in locating the holes reasonably accurately before hardening, saves a great deal of excess grinding, thereby relieving the Jig Grinder's load. On the other hand, the Jig Grinder, by grinding the holes directly, instead of merely establishing the locations, takes an enormous amount of tedious work from the Borer.

Both the Jig Borer and Jig Grinder employ the same measuring principle and, with it, the same convenient system of coordinate location. Coordinate calculations, once made, can be used all the way through the job, in boring the soft pieces and in finish-grinding the hardened parts. This is especially important in inspection, as seen below. To attain the fullest employment of both machines, coordinate calculations should be made ahead of time in the engineering office, saving the time of the machine operator.

Many of the small tools and accessories for setup and inspection purposes may be used with either machine. The bolts and straps, rotary table, work-holding precision vise, indicator and holder, edge finder and microscope are examples of these. This encourages uniform operating habits, with resultant common language for discussion of the various jobs by the men working on them.

Cutting tools, of course, are not interchangeable between the two machines. Proper selection of cutting tools, however, is important to the overall operation of the partnership. As an example, a set of end reamers, sufficiently undersize to leave a grinding allowance, should be available to the Jig Borer. The end reamer method is the most rapid method of finishing holes in the Jig Borer and, although not so accurate as single-point boring, is good enough for parts subsequently to be ground. A set of undersize end reamers for the Jig Borer is, therefore, a great asset to the Jig Grinder.

It is not the purpose of this chapter to describe the specific means of attaining high accuracy and speed with the Jig Borer or Jig Grinder. It is rather to show how the convenience of attaining these influences toolmaking away from indirect methods and compromises, and toward clean-cut, direct, interchangeable parts and assembly. Let us recall once again the three major steps in the hole location process:

1. Establishing the location.

2. Cutting, drilling, boring, grinding, etc.

3. Inspection.

Each Machine Its Own Inspector — The use of the Jig Borer and Jig Grinder for the first two of these steps is already recognized. Not so well recognized, how-

ever, is the enormous value of these machines to the inspector. *Before the job is removed from the machine*, immediately after boring or grinding, the inspector should be called. He can check the coordinate layout and run around all the holes with an indicator in far less time than they can be checked by any other means.

The reader may object to the practice of checking the work by the same means employed to produce it, contending that errors in fabrication simply "carry over" into the checking, that the piece will obviously "check the same as it was bored", and that the checking should be done by some independent device.

This is a perfectly natural and sound objection. On high-precision work especially, it is advantageous to compare the checking of the finished workpiece in the Jig Borer or Jig Grinder against two or three other standards, then to average *all* the results before assigning errors.

The differences between the Jig Borer and Jig Grinder and other good standards, however, especially over short distances, are in the realm of "half-tenths", infinitely smaller than the additional errors usually introduced by transferring the workpiece from one system of measurement to some other, although equally accurate, system.

This is the real crux and incongruity of the situation. Upholding our contention that there are small errors, or differences, between standards, we go to enormous amounts of trouble, always subject to the probability of introducing new errors greater than those we seek, when the workpiece is already in place and properly oriented with respect to the precise measuring system built into the Jig Borer or Jig Grinder.

To approach, in inspection, the accuracy attainable by Jig Boring or Jig Grinding is an extremely tedious procedure. One commonly employed practice is that of setting the piece up on a surface plate, checking heights of inserted plugs, comparing them with a height gage or stacks of gage blocks. In addition to the work of making close-fitting plugs, considerable calculating is necessary. Also, after checking the dimensions in one direction, the piece must be turned 90° to measure the distances in the rectangular direction.

The toolmaker's microscope, mounted on a compound slide, is a vast improvement over the surface plate and gage blocks, especially because of its built-in rectangular movement and homogeneous coordinate location system. When it is transferred to the compound, however, the workpiece must be re-oriented to it.

Many hours of time spent checking comparatively small boring or grinding jobs might be saved by checking the piece in the original setup, *while still in the machine*. Many steps, each with its possibilities for error, are eliminated. A few

favorable comparisons give the toolmaker confidence that the Jig Borer and Jig Grinder are fully as dependable as any other shop standard of accuracy.

In fact, a great many cases are found where independent inspection makes the work *appear* to be in error much *worse* than it actually is, Figs. 300 to 303. Errors in the independent system, plus errors in orientation to it, accumulate to large proportions. Methods and results of checking should be closely scrutinized before definitely rejecting Jig Bored or Jig Ground work.

Before proceeding with the description of re-orienting workpieces when transferring them from one system of measurement to another, a thorough consideration of the basic concepts of dimensions and tolerances is appropriate. There is a good deal of laxity and irrationality, even among engineers, in our thinking and talking about "tenths", especially in relation to hole *location*.

The expression "within a tenth" is inadequate, because it is subject to too many interpretations. Either it should be qualified by the user and its meaning defined, or a uniform connotation must be adopted for our everyday language. Failure to do this results in misunderstandings: time unnecessarily spent in attaining uncalled-for high accuracies on the one hand, or accusations of "phony tenths" on the other.

To make a start at pointing up the importance of correct interpretation, a very simple case, that of measuring a plug gage or gage block, provides an excellent example.

"Within a tenth" might mean one of two things:

1. A total range of error of a "tenth", or, plus or minus a half "tenth" from a nominal dimension.

2. Plus or minus a "tenth" from the nominal dimension, or a total range of error of two "tenths".

So we find a difference of 100% between two interpretations in this simple, single-dimensional case. What might it be on a master plate, gage, or drill jig, with respect to the *locations* of several holes?

1. The absolute center distance between *any two holes*, the total range of error being a "tenth", or, plus or minus a "half-tenth" from a nominal dimension.

2. The absolute center distance between any two holes, plus or minus a "tenth" from nominal, or a total range of error of two "tenths".

3. The distance from *each* hole to a common reference point, the total range of error for *each* hole being one "tenth", or, plus or minus a "half-tenth".

4. The distance from each hole to the common reference, plus or minus a "tenth", the total range of error for *each* hole being two "tenths". By this interpretation, the total *range of error* between *any two holes* might add up to as much as four "tenths", or four times that in (**1**), al-

though no hole deviates from the nominal by more than one "tenth".

Similarly, to verify, by inspection, the locations of the holes in any specific job, the inspector must measure:

1. The distance between two specific holes, or

2. The distance from each hole to some hole designated as a "starting point". It will be shown that this actually resolves itself into the same situation as (**3**).

3. The distance from each hole to an imaginary reference point, or imaginary system of dimensions, such as a coordinate location system, in *two directions.*

Up to this point, our discussion has been purely academic, no allowances having been made for the difficulties in handling the physical equipment for inspecting, or verifying positions of holes. Yet this is a vital part of the job. After interpreting the tolerance specification, the first question asked is, "how is the job to be checked, and what equipment is to be used?"

Each hole must be (a) picked up, or observed, and (b) related in some way to a standard of measurement. No such rigid device as is possible for checking plug gages may be used for measuring hole location. The surface of a plug gage or gage block is entirely exposed, and may be put under a sensitive and rigidly-constructed comparator for comparison with the standard. Surfaces of holes are internal, and cannot be approached with this equipment. They can be measured only indirectly through pins, indicators, or microscopes.

In general, one of three pickup methods might be used:

1. Indicating directly upon the surface of the hole. The point of contact is uncertain, especially in small holes, unless the indicator is held in some manner to ensure approaching the hole from a direction in line with its center, and unless the indicator may be rotated all the way around the hole. Otherwise, it necessitates exact knowledge of hole size, roundness and bellmouth, if any. To find the exact size of the hole, a tight-fitting, precision plug gage must be fitted to it.

2. Indicating one side of a tight-fitting precision plug. Indicating only one side of a hole or pin for location presupposes exact knowledge of size. A plug is far easier to measure accurately than a hole; in fact, the hole cannot be measured accurately without first making a plug. Indicating one side of a pin introduces the danger that the pin may not fit exactly, that it may be tipped in the hole, or that the hole itself may not be perpendicular to the surface of the workpiece. Extending this error to the outside of the workpiece through a plug gage serves only to accentuate the error. Poorly fitting pins are a major source of inspection errors.

3. Picking up the edges of the hole optically with a microscope containing a ruled reticle. This eliminates spring tension devices, such as indicators, but has

the disadvantage that only sharp corners may be observed accurately. The hole and the surface of the workpiece must be lapped to produce a clean, sharp edge. At any rate, two observations seldom agree within a "half-tenth" or "tenth".

In addition to observing, or picking up the hole, the observation or pickup is related to a measurement standard, usually by one of these three methods:

1. Inserting a stack of gage blocks between two pins, protruding from holes. This measures *directly* between two holes, without any intervening parts except the pins, and is accurate if skillfully done. Sensitive hands and great skill are required, especially in case of slender pins due to the danger of springing or spreading them. At any rate, it measures position in only one direction, along the chordal dimension, and does not relate it angularly. For these reasons, few toolmakers trust this method.

2. Standing the workpiece on its edge, or strapping it to an angle iron, referring all locations *to a surface plate* by transfer across the tops of fitted plugs, through the indicator and stacks of gage blocks. The location of each hole is determined by an *individual measurement* to the surface plate.

The relation between any two holes is found by subtracting one of these measurements from another. This has the disadvantages of errors previously mentioned, those of poorly-fitting plugs, attendant spring, out-of-parallelism, and the like. This checks the holes in one direction only, and requires accurate rotation through 90° to check the perpendicular dimensions.

3. Strapping the workpiece to a coordinate location device, such as the toolmaker's microscope or the Jig Borer or Jig Grinder, picking up holes with the indicator or microscope, and relating each hole to the coordinate location system, checking in two directions at the same time.

It is now seen that **(2)** and **(3)** resolve themselves, fundamentally, into the same sort of situation, in that, in both cases, hole locations are all referred to a *common base, not directly from one to another.*

A frequently-encountered pitfall is that of assuming as a "starting point", some specific hole or row of holes. It often happens that all dimensions on a given drawing are built up from a basic center line, or base line. For this reason, holes on this line are usually the first ones picked up. However, there is fully as much danger of error in picking up these holes as there is in picking up any of the others. The theoretical base line, therefore, must be established from the average of the errors of all the other holes, and may not be definitely determined until all have been checked. Usually it is necessary to reorient the workpiece with respect to the theoretical base line to assign final errors against each hole.

Now, if a hole is off location ±.0001″, and the inspector makes an error of ±.0001″ in checking it, the range of possible error is again increased. A hole actually off .0001″ might appear in error .0002″ by the inspector, and be rejected. Inversely, a hole which appears off .0001″ to the inspector might actually be off .0002″.

If this extreme exists in opposite directions on two holes, when referred to a common base, they might be off, relative to each other ±.0004″, a total range of error of .0008″ between two holes!

A simple example of the necessity for re-orientation is represented by inspection charts, Figs. 300 to 302. In each case, the holes on the horizontal center line were used as a base to check vertical distances, and the holes on the vertical line as a base for horizontal distances. The inspector shows deviations as found by him. Substantial differences between First Inspection and Second Inspection are noted, Figs. 300 and 301. Some of these may undoubtedly be assumed to be the result of errors in picking up the base holes. For example, if the workpiece had been set up the first time, Fig. 300, .0001″ lower and .0001″ farther to the left, inspection results would have appeared as shown in sketch, "First Inspection Re-oriented." Similarly, it appears that, the second time, Fig. 301, it should have been .0001″ higher, and .0001″ to the left. Re-orientation in the inspection system would have produced results shown in sketch, "Second Inspection Re-oriented".

Averaging the re-oriented sketches indicates the dimensional errors in Fig. 302, which apparently should be further oriented to sketch entitled, "Re-orientation

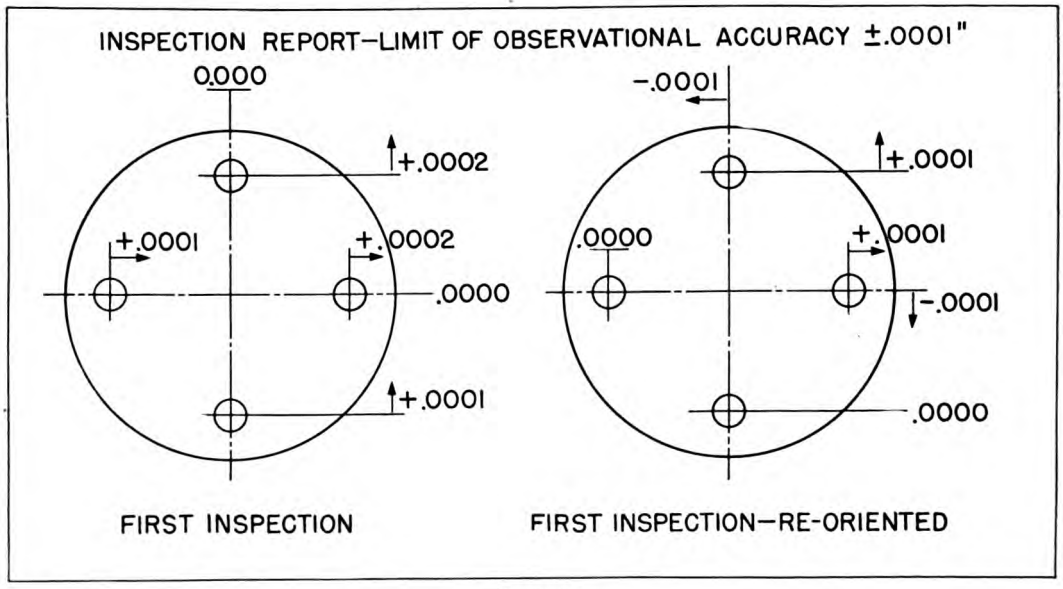


Fig. 300

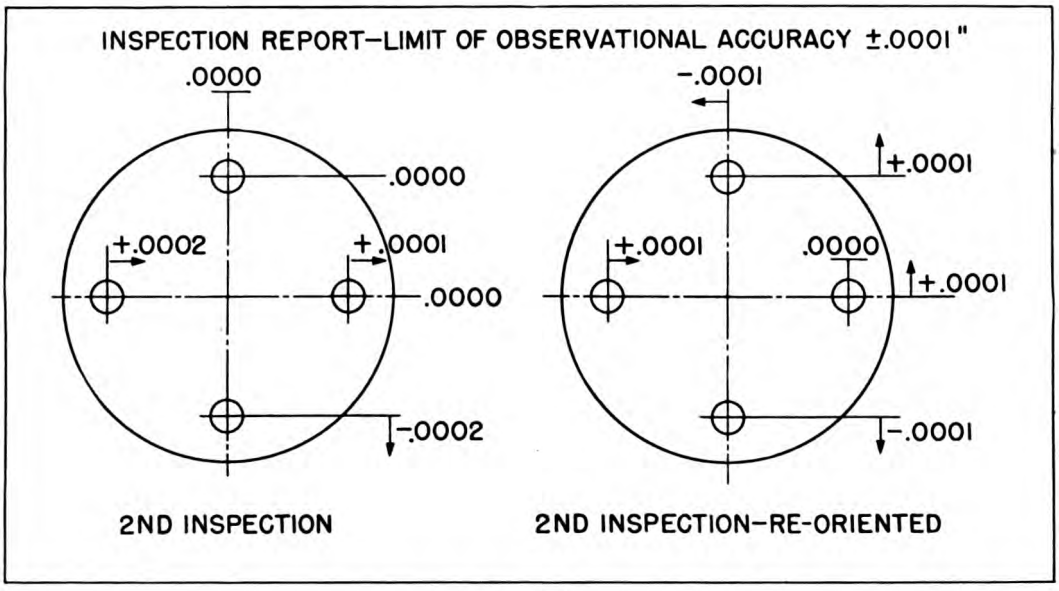


Fig. 301

of Average — Probable Actual Locations of Holes in Piece Part". These figures show the *probable* true locations of the holes. This cannot be stated with any definite degree of certainty, however, since our measuring equipment is assumed to have an observational limit of accuracy of ±.0001". In most cases it is also necessary to relate all holes to the periphery of the workpiece or to an edge. This supposition has been omitted from this example to minimize confusion.

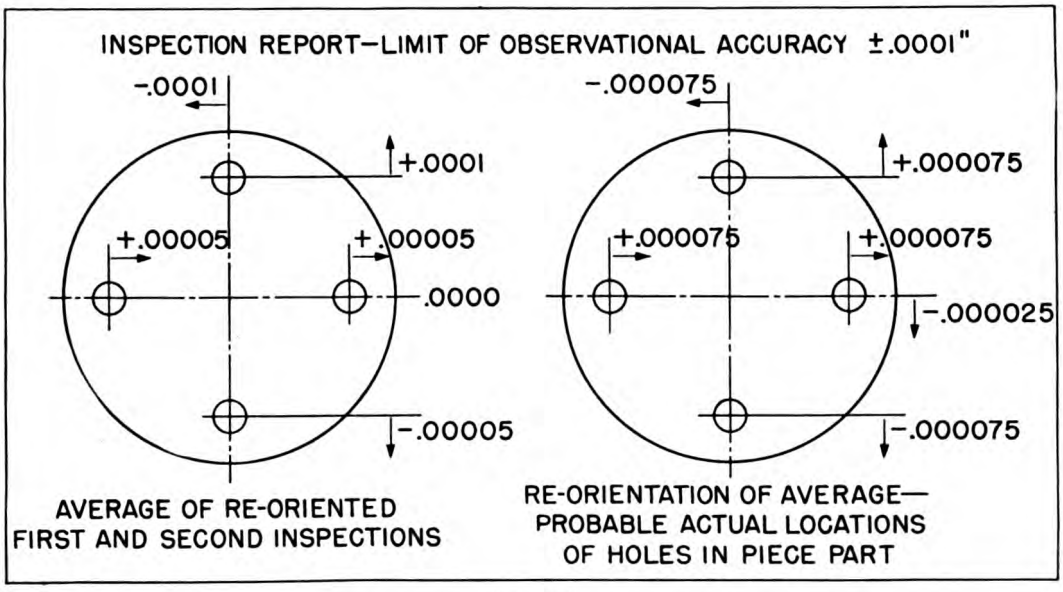


Fig. 302

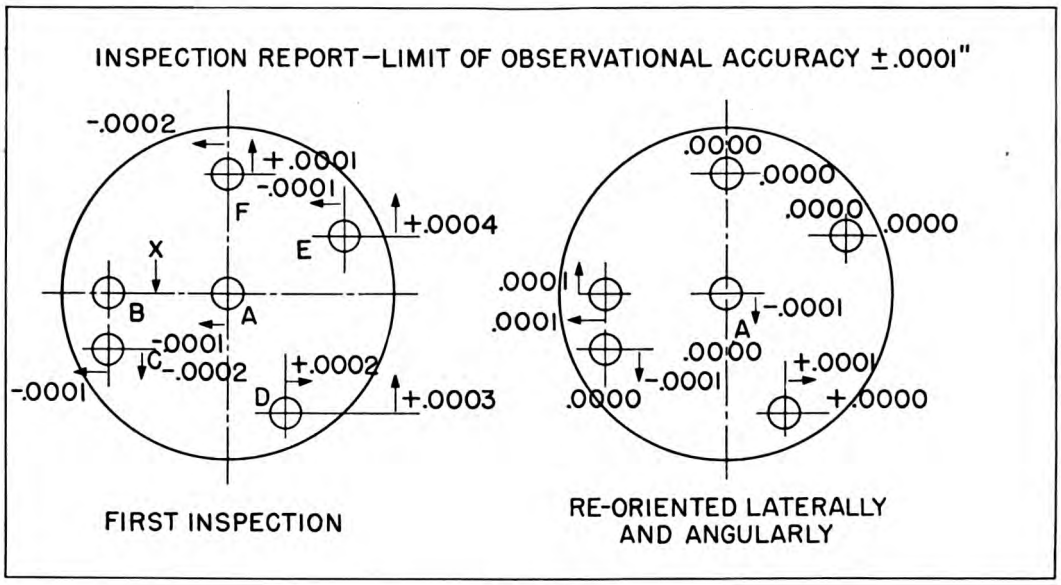


Fig. 303

The above example represented probable mis-orientation of pickup in parallel directions only. If errors in picking up the two holes on the base line are made, one in one direction and one in the other, a great exaggeration in some apparent errors might result.

Directions of the errors in Fig. 303, for example, show that the workpiece should be moved to the left and, at the same time, rotated clockwise. The nature of the errors indicates that the reference holes, A and B, were misaligned in different directions when the pick up was made. The workpiece should be rotated approximately around point X, so that hole B is moved upward and hole A moved downward. The resultant chart of errors might then appear as in sketch entitled, "Re-orientation Laterally and Angularly". The largest errors have now been canceled out; the remaining ones might be either errors in fabrication or inspection, or an accumulation of both. It should not be assumed that re-orientation alone is sufficient. Each measurement should be taken enough times that a reasonable average may be derived.

The above examples have assumed that the workpiece has been removed from the Jig Borer or Jig Grinder and set up in some other system for checking. It is for this reason that so much time-consuming re-orientation is required. If checked in the Jig Borer or Jig Grinder, this is largely eliminated.

This leads us to the question, "if it is Jig Bored or Jig Ground, what good does it do to check it on the same machine?" It ought to check the same as it was bored or ground. It will probably not check *exactly* as bored, however. During operation as a

boring or grinding machine, the Jig Borer or Jig Grinder is subject to temperature changes, strains from cutting tools and vibration, all resulting in minute changes from true position. A change will sometimes be noted if the indicator is moved from one side of the spindle to another. This results from out-of-roundness of spindle, and, although minute, when added to other errors, can actually be found. For this reason, the indicator should always be held in the spindle so as to face the same direction as the cutting or grinding.

After the Jig Boring or Jig Grinding, the machine is employed for inspection purposes and, since no cutting is being done, it will be free from vibration and stresses. Also, since the inspection is done during a short period of time, serious temperature changes cannot take place.

For these reasons, some discrepancies will be found. The amounts are minute and should be expected, on the average, to be mostly in the same direction. A small amount of parallel re-orientation will cancel them out.

Use of the rotary table for circular indexing introduces additional errors, both in fabrication and in checking. Operators frequently notice that rotary table work does not seem to check as accurately as that done by rectangular coordinates, and question us regarding the accuracy of the dividing system.

We do not believe it possible to attain as accurate location by indexing as can be done by rectangular coordinates, *however accurately divided the rotary table may be.* Although this statement may come as a shock to readers who have not studied the situation, it is readily understood when analyzed.

Errors in the rectangular coordinate location system must be included even when doing rotary table work, since distances from the center are measured by it. Errors from temperature changes and machine vibration must be also included, the same as in rectangular work.

The rotary table principle adds several other errors to these:

1. Errors in picking up the center of the rotary table with respect to the machine spindle.

2. Errors in picking up the center of the workpiece with respect to both the rotary table and machine spindle.

3. Errors in the dividing system.

4. Errors in *reading* the dividing system.

The effect of any of the above errors may be *doubled*, because of the principle of rotation. For example, if the center hole of the workpiece is eccentric to the rotary table by .0001″, the holes on one side of the circle will be .0001″ too close to the center hole, while those on the opposite side will be .0001″ too far away. The difference between these distances will be .0002″.

In some cases, all the above errors

might happen to occur in the same direction and accumulate to large amounts. For these reasons, especially on high precision work, it is better to work with rectangular coordinates, and eliminate other sources of trouble. If the rotary table is used, extreme care should be taken to keep each individual error at a minimum; the accumulation might grow to alarming proportions.

Laxity and misinterpretation of statements of accuracy apply to rotary table divisions as well as to rectangular measurements. We frequently hear expressions referring to angular divisions such as "within five seconds", or "within ten seconds", or "within a tenth on an eight-inch diameter". The full expression "within ± five seconds", or "within ±.0001″" should be employed.

As in rectangular coordinates, an angular zero, or reference, is used. Care should be used in taking any specific hole as a zero, for the same reason as that for taking any hole, or row of holes, as a reference in rectangular measurements. There is fully as much chance of error in boring, grinding or checking, or in the dividing system itself, at the zero point as at any other.

Plugging Plates Together — It sometimes happens that two or three hole location gages, or jigs, may be made exactly alike. They can be checked against each other by pushing snug-fitting plugs through all the holes in both plates. This is somewhat effective, but has its drawbacks also. Superior workmanship must be achieved in all holes, and pins must not be appreciably loose; otherwise the method is deceptive. Very little force is required to bend or spring the pins, and the plates will go together smoothly even though the locations are incorrect. At best, the plates are merely compared, no reference being made to any standard.

The most dependable check is made by checking the piece in some rectangular locating system, and indicating each hole all around, over its entire surface. The system best-suited to this is the Jig Borer itself. The toolmaker's microscope is also excellent, of course, *provided* all holes have finely-finished sharp edges. In some cases, especially in holes too small to approach with the indicator, or irregular forms, checking is done more effectively with microscopes. For this purpose, microscopes are available for both the Jig Borer and Jig Grinder, converting them to efficient inspection machines.

General Remarks About Inspection Procedures — The operator may be confused between out-of-roundness and out-of-location. When he makes a setting and finds the indicator reads .0002″ higher on one side of the hole than the other, his first reaction may be that the hole is out-of-round by that amount. This probably is not out-of-roundness, but out-of-location.

Moving the table slightly to correct location brings the readings equal all around, showing the hole to be, in actuality, not out-of-round, but merely off-location.

The preferred type of indicator is that with the extension lever-type tip, such as the "Last Word", "Federal", or "Ideal". Plunger-type indicators require additional levers to transmit motion in the right direction. In addition to increasing bulk and clumsiness, the added levers reduce the sensitiveness and accuracy. To overcome the necessity for reading the indicator from the back of the machine, or with a mirror, various rotating devices have been made to transmit the movement while holding the indicator stationary. These also reduce the sensitiveness. For these reasons, direct use of the lever-type indicator is recommended.

Usually a "thousandth" indicator is sufficiently sensitive. Since the hole is indicated all around, any locational error is doubled on the indicator dial. This compensates the lack of high magnification in the "tenth" indicator. In fact, unless held very rigidly, the "tenth" indicator loses as much in sensitiveness because of its greater internal friction as it gains from magnification.

Recommended practice for checking is to set the table position so the indicator reads true all around the hole. Run the indicator up and down in the hole to obtain a good average reading. Compare the actual table settings with the calculated coordinates, to which settings were made during fabrication. Differences between figures represent *actual* errors.

Due to causes previously mentioned, slight errors will sometimes be found. As a rule, they will be in one direction, all plus or all minus, and mean that a temperature change has moved the whole coordinate location system during the time lost between machining and inspecting. These errors cancel themselves out by *parallel* re-orientation.

The use of the Jig Borer and Jig Grinder as an inspection device is in many plants spontaneous. The great saving in time, together with its more direct manner of getting accurate results, far outweigh the disadvantages. Experience soon convinces the toolmaker that the Jig Borer or Jig Grinder is *fully as dependable as any other shop standard.*

There are, in fact, cases where purchasers have stated their intention of installing the Jig Borer in the inspection department, employing it *only* as an inspection machine. Some have even asked for omission of the motor and drive mechanism, preventing its use for any other purpose.

One, upon being asked for suggestions in design to make the Jig Borer a more efficient inspection machine, replied, "It already contains the required elements. How else would you build it?"

In addition to saving time, the capacity of the tool inspection department is greatly increased. Considerable inspection equipment is still necessary, of course, but a good deal of it is supplanted by the use of the Jig Borer and Jig Grinder as inspection machines.

Working to Figures Instead of "To Fit" — The largest contribution of the new facility in hole location is the more direct trend in the toolmaker's thinking. He learns to work to figures instead of "to fit". Compromises, substitutes, and laxity are rapidly dropped. One of the compromises is the selection of materials. The bugaboo of hardening distortion has often led to the use of steels made for resistance to deformation rather than resistance to wear. Dies, especially, suffer from this. Since labor is by far the most expensive item in the building of dies, why compromise die life by using unsuitable materials?

Dies are not the only place where substitutions are made. Bodies of fixtures, jigs, and gages are often left soft for fear of hardening distortion. Some may claim that it is unnecessary to harden the bodies because bushings are inserted to take the wear. There are three good reasons for hardening:

1. The danger of shearing the hole in the body when pressing in the bushing, thereby disturbing its position. This is unlikely in a hardened body.

2. The danger of expansion and distortion of the body from the pressure required to hole the bushing. Whereas bushings pressed into soft steel bodies require .001″ to .002″ press fit, they will stay tight in hardened bodies with only .0002″ press fit. This is especially important in jigs or gages with a large number of holes and where high accuracy is required. Distortion from this cause is negligible when the body is hardened and ground.

3. The wearing out of the body from frequent replacement of worn-out bushings is also minimized by hardening and grinding.

Other compromises eliminated by the convenience of the new partnership are those brought about by the inherent tediousness and inaccuracies of the old hole-locating methods. Transferring, carriers, and master plates were compromises employed partly because no method was available for positively attaining location, and partly to avoid the necessity for correcting hardening distortions. The toolmaker was constantly on the horns of a dilemma. He had the choice of either accepting the errors introduced by distortion, carrying them along by transfer and gambling that the tool would pass inspection, or the long, drawn-out process of correcting them.

The coordinate location system, built into the Jig Borer and the Jig Grinder, encourages dimension-mindedness. The correct materials for the job can be employed,

and the toolmaker gradually forgets the old compromises. In their place, he substitutes direct thinking and better overall accuracy habits.

Toolmaker's Talents More Productively Employed — The toolmaker, being relieved of the hole locating job, is released for other work, where his skill is vitally needed. The old irritation from the tedious repetition of his steps of inspection and correction is gone. His job takes on a new dignity, and his mind is free to study basic parts of the job, such as design, supervision, and assembly work, for which his many years of experience have fitted him. His outlook is brighter and also, the chances are, his relations with "The Boss".

Apprentices, too, benefit from the change. They now learn the direct, accurate way of toolmaking. Apprentices learning the trade have often found, upon asking experienced toolmakers how to locate holes, that they got about as many different answers as there were toolmakers. Most toolmakers developed tricks and kinks of their own, to suit certain conditions, and the apprentices, not having sufficient background, were confused and discouraged. Apprenticeship is now more rewarding and stimulating. Apprentices get a chance to see a wider variety of tool work; they cover the basic work faster and learn the trade more quickly.

Result: A New Era In Toolmaking Through Interchangeable Parts and Assembly.

Lower Tool Cost and Increase In Toolroom Capacity — The influence of all these factors upon the toolmaking industry is far-reaching. Its full effect is not yet felt, since the use of the principle of interchangeable parts-and-assembly in toolmaking is far from universal. Its possibilities are as revolutionary to the toolmaking industry as they have been to mass-production. Although the cost of the tools goes down, their value goes up.

The reasons for lowered cost are many and the major ones are recalled here:

1. Saving of overall toolmaking hours.

2. Saving of much extra work, such as accurately squaring up of parts before laying out or buttoning. Many parts require only that holes bear accurate relationship to each other, not to edges of parts. When laying out or buttoning, accurate squaring up is necessary only as an intermediate step, necessary for the making of the tool, but not necessary to the final result.

3. Saving of actual layout and buttoning.

4. Saving of making special tools, carriers, master plates, spotting tools and other special tools used with transferring process.

5. Saving of enormous amounts of time spent in inspection, correction, re-inspection, re-correction.

6. Increase in toolroom capacity.

These savings are reflected in increased capacity, not only for the individual toolmaker, but also to the whole toolroom. Not only do these machines do their work more efficiently, but they take much less floor space in proportion to the work done than the lathes or internal grinders formerly employed.

In spite of their lower cost, tools made by Jig Borer-Jig Grinder partnership methods are actually of greater value to the user. There are many reasons for this:

1. Quicker Delivery of New Dies to Your Pressroom — Under conventional toolmaking practices, wherein the holes are transferred from the die block after hardening and all parts thereafter are made "to fit" instead of to figures, the die block must be made first, and hardened, before any of the other parts can be made. The stripper and punch plate must wait until the die is hardened, since there is no way to predict the condition or positions of any of the holes in it.

Use of the Jig Borer-Jig Grinder partnership permits a degree of specialization not possible by transfer methods. Since all parts are made *strictly to dimensions*, the die, stripper, and punch plate may be made concurrently. Development of more accurate habits also permits the making of small punches and bushings by other workers at the same time. In this manner the delivery of new dies to the pressroom is speeded up enormously.

As an example, the ten-station progressive die, Fig. 211, if made under conventional practices, would represent about 2,000 man-hours of labor. Since the parts would have to be made in progressive steps, only one or two men could work on it at a time. Delivery, therefore, would require about six months.

Interchangeable manufacture permits all the parts to be made concurrently. The Jig Bored die sections, after hardening, are assembled completely on their own dowels in the die shoe. All holes are then Jig Ground. The stripper, hardened stripper inserts, and punch pads are Jig Bored and Jig Ground during the time the die blocks are being fabricated. Six or eight men work on the various parts at once. Man-hours are cut to 1,000 and the die is delivered in six weeks! Moreover, due to its high accuracy, its life is two to ten times that of an unground die.

Another outstanding example of the interchangeable parts-and-assembly principle in toolmaking is the complex quadruple die, shown disassembled in Fig. 304, for producing the splined washer, Fig. 305, four at each press stroke. Accuracy requirements are exceedingly stringent; the material is thin (.010″); the fragile blanks must be kept flat and free from burrs. Blanks must be "pushed through" for stacking on stacking rods.

Moreover, since the piece part is for a vitally-needed project, the tools must be

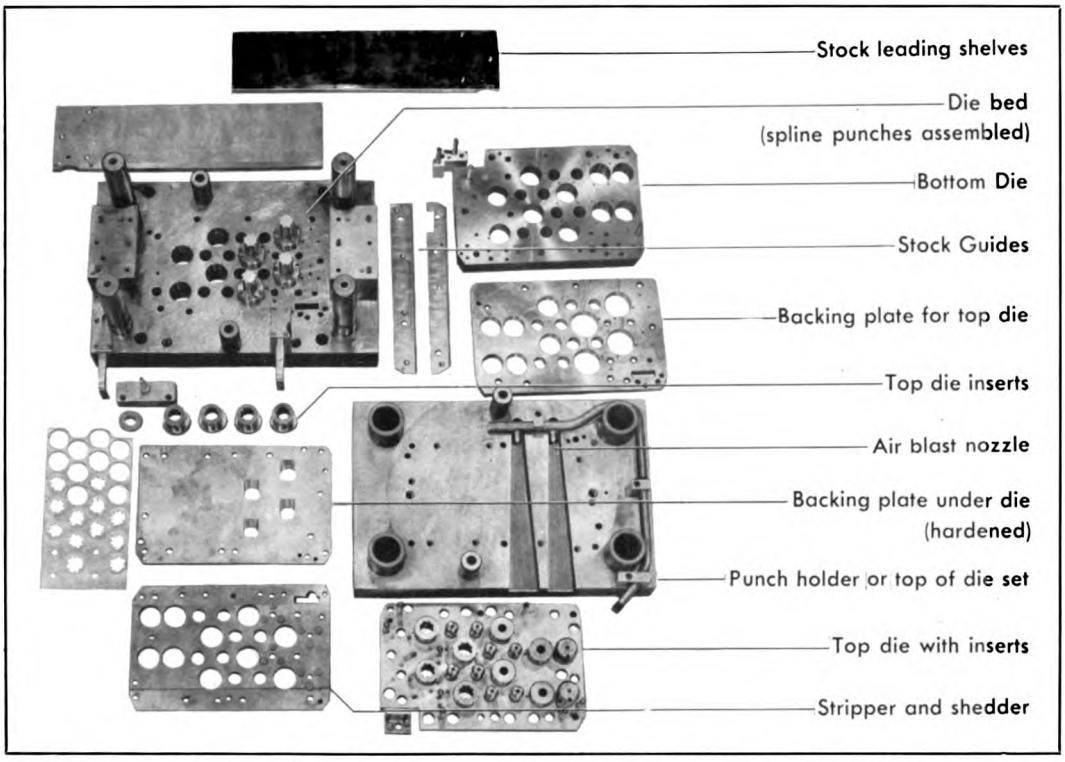
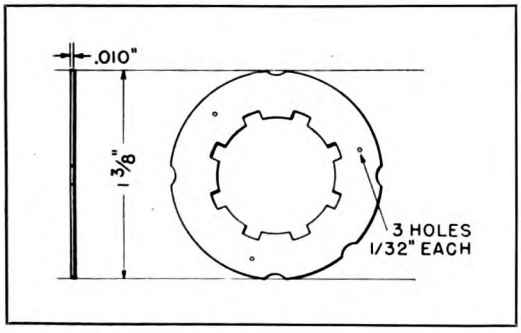


Fig. 304 — Quadruple dies produced interchangeably in The Moore Special Tool Company's toolrooms.

produced in the shortest possible time. Tool parts must be made by direct methods. "Tinkering" cannot be tolerated; dies must run immediately upon installation into the press. To obtain the required production many of these quadruple dies were required. Ten were made on a single order.

To maintain flatness and yet permit stacking, a combination compound and progressive die design was adopted, the splined center hole and most of the periphery being cut in the compound station, the remainder of the periphery being cut in the final "push-through" station. The first station pierces the three small holes (.030″ diam.) in two rows, and round center holes



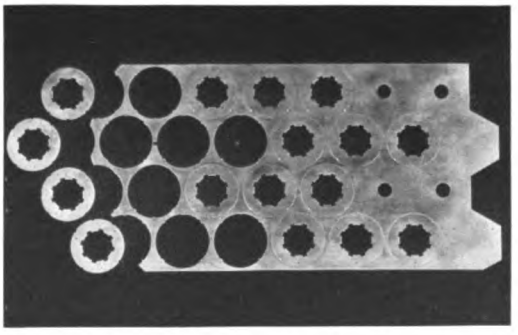


Fig. 305 — Dimensional details and scrap — splined washer, produced by quadruple die, Fig. 304.

for the other two rows. These center holes are used for piloting the second station, where the three small holes in the other two rows are pierced. The second and third stations act as the compound stations, where most of the cutting is performed.

The slugs from the splined piercings are pushed upward through the die inserts. This accounts for the milled-out air chambers in the punch plate. When the slugs reach this chamber, they are blown out of the punch plate by air blasts emanating from nozzles terminating the air pipe shown.

The periphery of the blank is not completely separated from the scrap in these stations. It is left attached at five points corresponding to the detents or notches, visible in Fig. 305. Carried by these points, the blank proceeds to the final blanking stations, where only these detents are cut, the punch pushing the blank through the die to stacking rods.

Lack of space prevents placing the blanking stations immediately adjacent to the compound stations. In each row they are separated by two inactive stations. These two stations are piloted in the splined hole. In addition, two rows are piloted in the scrap *after blanking*. These final pilots are cleared at the detents, so the piloting is performed on the round surface cut in the compound station. Thus, seven stations comprise each of these two rows. In view of the many moves in this die and the high precision required, the piloting is of prime importance, and the distance between all stations must be alike within small limits.

To produce a die like this by old-fashioned hit-or-miss methods would be a practical impossibility; it would undoubtedly be made one-at-a-time, instead of quadruple. For comparable production, forty dies and forty presses would be required, instead of ten.

This die is possible today mainly because accurate hole location can be attained. Even if sufficient error could be tolerated to accept hardening distortion, transferring the errors back through the hardened die into the other plates, one die would consume the best part of 3,000 man-hours of labor. Since parts could only be made progressively, the job would be in the one-man class, requiring at least a year to build. Actually, the first of these dies was finished in three months; all ten were delivered five months after receipt of order.

The reason for this phenomenal performance is that all parts were made to pre-engineered dimensions by Jig Boring and Jig Grinding, Fig. 297, even to the dowel holes in the compound station inserts. Even the detents in the final blanking punches were Jig Ground. Detents in the blanking dies were inserted round pieces, set into Jig Ground holes, Fig. 306.

Even the assembly part of this job was

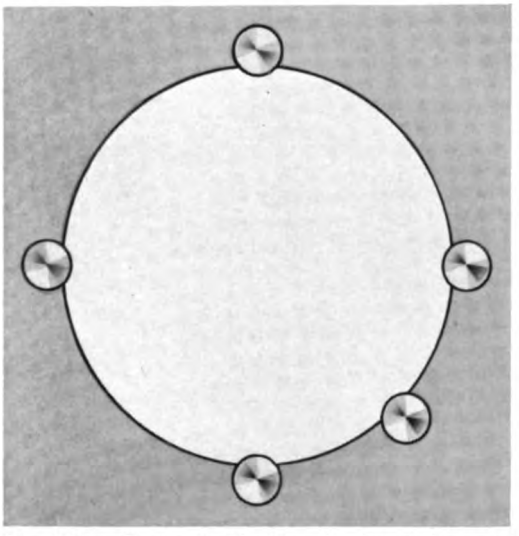


Fig. 306 — Detents in blanking die formed by round pins inserted into Jig Ground holes.

too big for one man to handle. Assembly of the various dies was handled by several toolmakers, some of whom had had no contact with the job in its early stages. At times, as many as twenty-two men were working on this job concurrently.

Average total man-hours to produce each complete quadruple die: 1,540.

Total Jig Boring for each die: 185 hours for 260 holes, size range $\frac{1}{32}$" to $1\frac{7}{8}$".

Total Jig Grinding, each die: 125 hours for 150 holes, size range $\frac{1}{32}$" to $1\frac{3}{8}$".

2. Quicker Repairs to Old Dies — Die parts made to dimensions when broken or worn out can be quickly duplicated, Fig. 307. Breakage or failure in service of these die parts threatened to hold up production on badly needed items. Telegrams or phone calls to the supplier of the original tools revealed that, in some cases, duplicate dies, in process but still unfinished, contained the same parts, made to identical

Fig. 307 — Replacement die parts, engineered and Jig Ground to dimensions.

dimensions. These parts were shipped to be assembled into the old dies. In other cases, where not in process, they were made from scratch *to dimensions.* In every case these parts interchanged exactly with the old parts, and production was resumed.

3. Longer Die Life — The length of life of a tool is determined, chiefly, by two major considerations: the choice of materials for wear-resistance and the accuracy of alignment of its parts. The very fact of its being made on an interchangeable basis is patent proof of its superior accuracy. Furthermore, since holes can be corrected by grinding, compromises in materials are no longer necessary. Those best suited to the job can be employed.

From a die life standpoint, dies for electrical lamination stampings, Fig. 308, present one of the toughest wear problems.

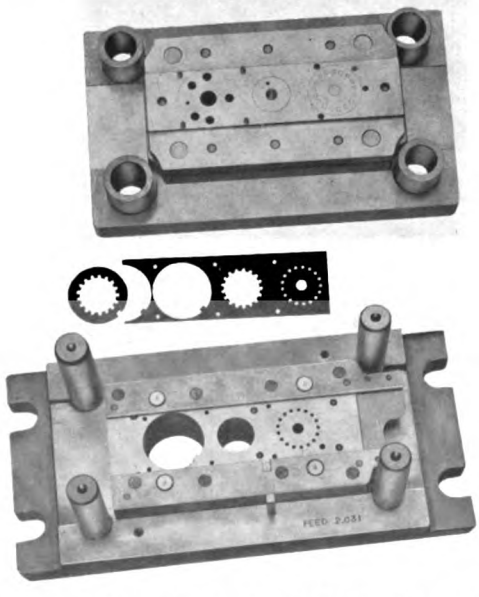


Fig. 308 — Dies producing electrical laminations require the ultimate in long life.

The stock to be cut is thin and of an abrasive nature. Clearances between punches and dies must be small, but uniform. Laminations must strictly interchange and are made in enormous quantities. Die life, therefore, is a vital factor in the cost of the stampings. Dies for these are made from special wear-resistant steel, and must be ground all over to remove scale and decarburization to maintain hard, sharp cutting edges.

4. Increased Manufacturing Capacity — The superior accuracy of these tools saves much trouble in other ways, too. Usually new dies as complex as this require a good deal of "tinkering" to get them running. The usual reason for this is misalignment of punches or slight errors between the feed and the pilots. They usually require tinkering every time they are set up and further tinkering to keep them running. These difficulties are largely removed when extreme accuracies are employed in the making of the die. The investment in toolmaking equipment may, at first glance, appear heavy. Dividends, however, are enormous.

Trouble-free operation insures maximum manufacturing capacity. A good share of the lost time in pressrooms or other manufacturing facilities is caused by tool troubles, breakdowns, or parts spoilage. Management, so prone to criticize production departments for lost time, should first examine the type of equipment in its toolrooms where a good part of the troubles originate.

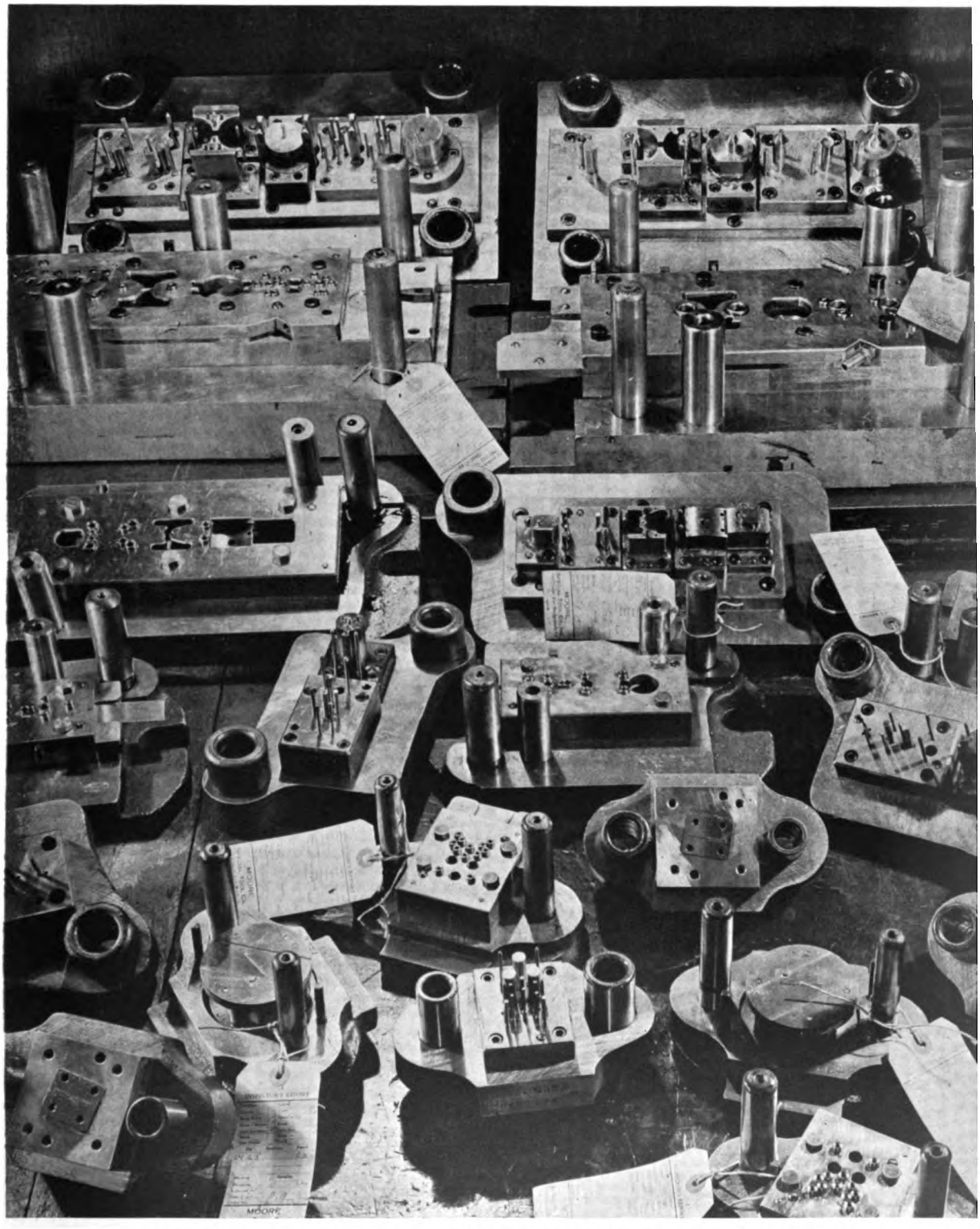


Fig. 309 — $25,000 worth of Jig Ground dies. Jig Grinding is an insurance guaranteeing greater return on your investment.

Better Value of Tools as Investment — Special production tools and dies represent a large proportion of management's investment in its enterprise. For its best protection, it is anxious to see the results from its expenditure delivered in the shortest possible time and in the best condition. Its dividends are measured in terms of the length of life and number of parts produced. The soundness of the investment is a direct reflection of the excellence of workmanship, accuracy, and choice of materials. The group of tools shown in Fig. 309 is a good example of the assurance of the soundness of management's investment by demanding Jig Borer-Jig Grinder partnership methods in the manufacture of its tools.

Better Value of Product to Consumer — It never occurs to the consumer, when deciding upon a purchase, to investigate or question the manufacturer's toolroom methods. That's because, automatically, his dollar ballot votes for the item which, in his opinion:

1. Looks better.
2. Works better.
3. Lasts longer.

This process in our industrial democracy is the lever which continuously forces manufacturers to find and use every improvement toward that end. What the consumer doesn't realize, and what too many manufacturers still don't realize, is that this must start in the toolroom.

Better and cheaper piece parts make for better and cheaper consumer items. The corollary also holds that better and cheaper tool parts make for better and cheaper tools.

The Industrial Revolution is too often considered as having happened in the remote past and over with. On the contrary, it is as continuous as motion, and will be a part of our lives until the far-off day of Utopia.

The producer who doesn't accept that principle in his toolroom as well as in his manufacturing processes cannot hope to survive in the expanding era of interchangeable manufacture.

WOODWORTH

CIRCULAR TABLES

OF

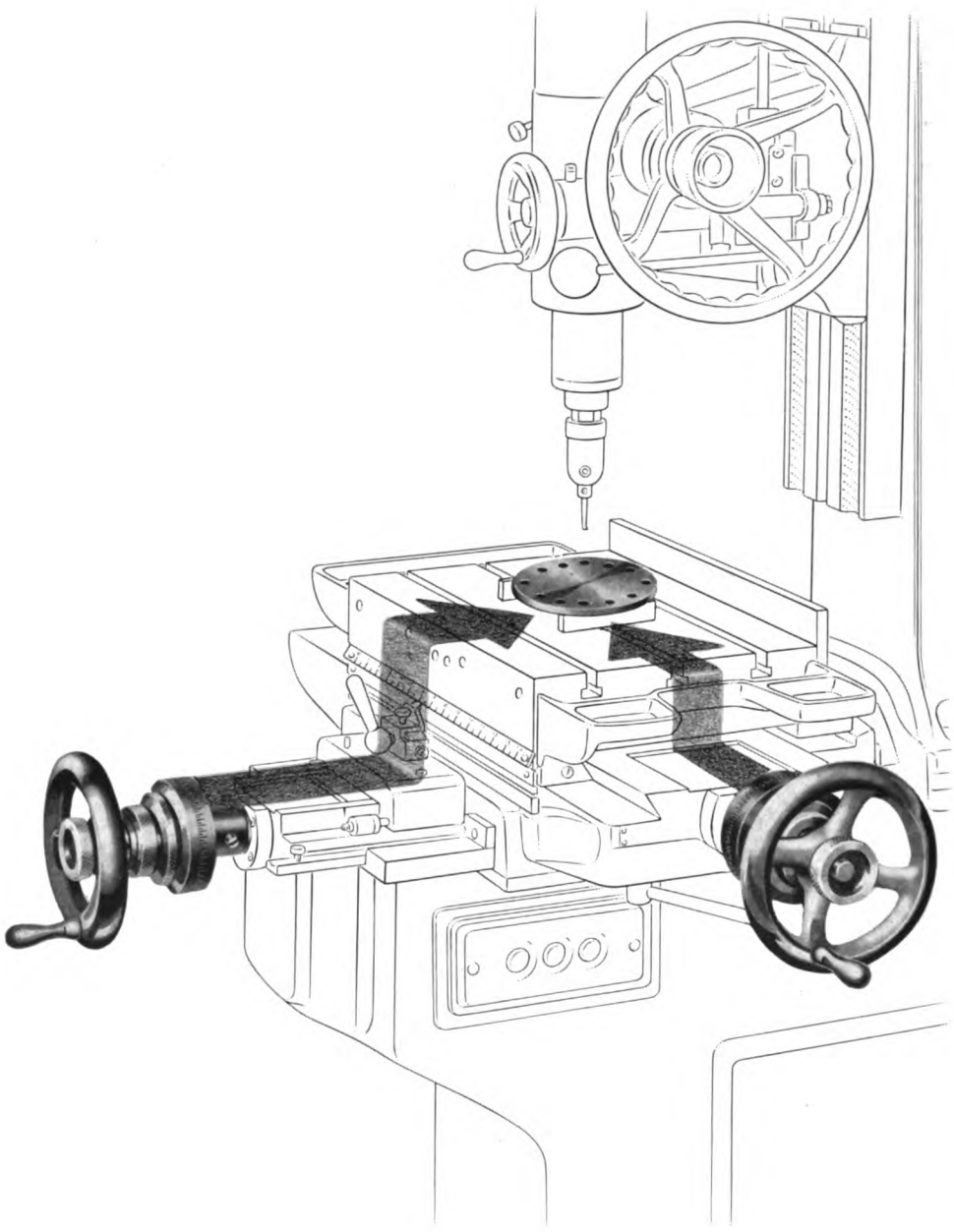
Coordinate Factors and Angles

by

W. J. WOODWORTH

J. D. WOODWORTH

Every effort has been made to assure accuracy in computing and publishing these tables. However, neither The Moore Special Tool Company nor the Woodworths can assume any responsibility for errors therein.



Partnership of Woodworth Circular Tables and accurate lead screws built into Moore Jig Borer and Jig Grinder speed table settings.

INSTRUCTIONS FOR USING

WOODWORTH CIRCULAR TABLES

HOLES ON CIRCLES may be laid out either in polar coordinates (angle and distance) or in rectangular coordinates. Polar coordinates, used with the rotary table, are undoubtedly the more convenient, and the easier to calculate. Rectangular coordinates, however, are inherently more accurate, due to the additional inaccuracies introduced by the rotary table principle (please refer to pages 243 and 244).

Calculating the coordinates in either case is no small job, especially when the number of holes is large.

Figuring the angles alone is a tedious, time-consuming operation, Fig. 310.

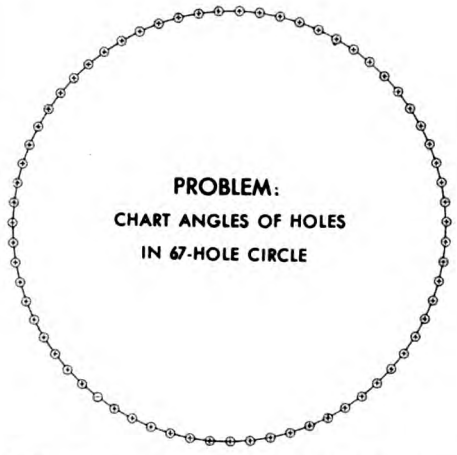
When calculating rectangular coordinates, figuring the angles is only part of the job. After the angle and distances are known, the distances from the center must be multiplied by the cosines and sines of the angles to reduce them to rectangular distances, which must be either *added to* or *subtracted from* the coordinates of the center of the circle to find the rectangular coordinates of each hole, Fig. 311.

W. J. Woodworth, of Mineola, Long Island, N. Y., a toolmaker, tool designer and tool supervisor of 40 years' experience, recognized the difficulties in these calculations. With his son, J. D. Woodworth, he set about developing tables to enable Jig Borer operators to obtain the correct figures with the least effort.

The cost-saving features of these tables have been thoroughly demonstrated over a period of two years prior to publication in this book. Richard F. Moore, president of The Moore Special Tool Company, states, "It would be difficult to evaluate in dollars the substantial savings which have resulted from use of the Woodworth Tables in our toolroom. To say that they save their cost on a single job is a gross understatement."

Application of these tables to polar coordinates is obvious. The angle from zero to any hole, read directly from the tables, together with the radius of the circle, establishes the location of the hole.

Calculation of rectangular coordinates,



360° ÷ 67 = 5 Degrees 22 Minutes 23-19/67 Seconds
Starting at zero, we add and tabulate as follows:

Hole No.	Degrees	Minutes	Seconds
0	0		
1	5	22	23-19/67
Add	5	22	23-19/67
2	10	44	46-38/67
Add	5	22	23-19/67
3	16	7	9-57/67
Add	5	22	23-19/67
4	21	29	33-9/67
Add	5	22	23-19/67
5	26	51	56-28/67
Add	5	22	23-19/67
6	32	14	19-47/67
	etc.	etc.	etc.

Fig. 310 — Steps required to calculate angular position of holes on circle. To prevent cumulative error each small fraction of angle must be added every time.

even *with* the Woodworth Tables, is necessarily somewhat more complex than for polar coordinates, since it involves multiplication of the diameter of the circle by a tabulated factor. The diameter being a constant throughout the calculation for any specific circle, the work is very conveniently done in a calculating machine.

A comparison between Figs. 311 and 312, however, reveals that the use of this

Problem: Calculating rectangular coordinates of holes on circle *without* Woodworth tables:

1. Determine coordinate location, in both directions, of center of circle.
2. Compute angle of each circular division as in figuring polar coordinates.
3. Determine quadrant in which each angle is located.
4. Find relation of each angle to horizontal line, by subtracting from 90°, 180°, 270°, or 360°, or vice versa.
5. Multiply co-sine of angle by radius of circle.
6. Add or subtract result to or from coordinate of center of circle.
7. Multiply sine of angle by radius of circle.
8. Add or subtract result to or from coordinate of center of circle.

Fig. 311 — Steps in calculating rectangular coordinates of holes on circle without *Woodworth tables.*

table results in an enormous saving of time, with less possibilities for error.

Use of the Woodworth Tables in calculation of rectangular coordinates is best explained by example, Figs. 313 to 316.

Steps in figuring rectangular coordinates *with* Woodworth tables:

1. Determine coordinates of "A" and "B" lines (tangent to circle).
2. Multiply "A" factor by diameter of circle.
3. *Add* result to coordinate of "A" line.
4. Multiply "B" factor by diameter of circle.
5. *Add* result to coordinate of "B" line.

Fig. 312 — Woodworth tables eliminate work shown in Fig. 310. Also steps 2, 3, 4, of Fig. 311, which represents about three-quarters of the necessary calculation time, with a proportionate insurance against errors in calculations.

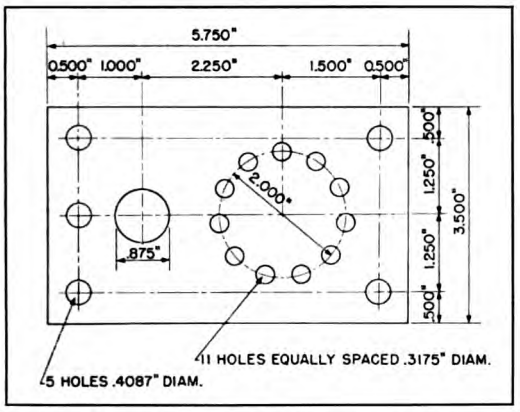


Fig. 313 — Conventionally dimensioned drawing.

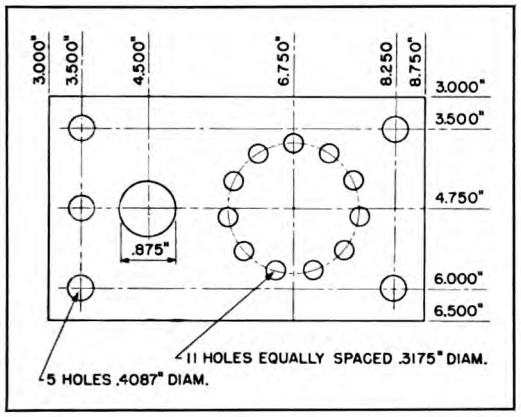


Fig. 314 — Coordinates established for dimensioned holes and center of divided circle.

First, rectangular coordinates of dimensioned holes and center of divided circle are determined, Fig. 314.

Next, the coordinates are calculated for the *left hand* and *upper tangents* of the divided circle by subtracting the radius of the circle from the coordinates of the center, Fig. 315.

Next, look in the 11-hole table for the A and B factors for each hole. Multiply these factors by the diameter of the circle of holes, and add their products respectively to the coordinates of the left-hand and upper tangents. Place these figures on

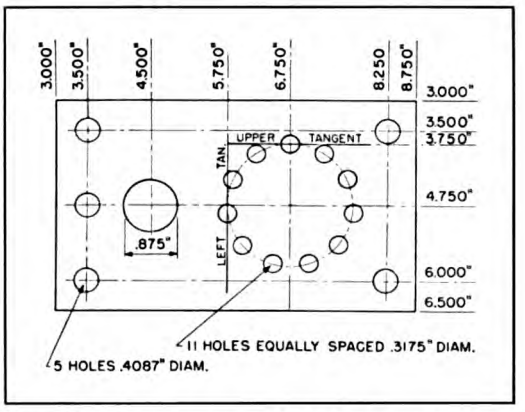


Fig. 315 — Coordinates established for left hand and upper tangents of divided circle.

the drawing as shown at hole No. 8, Fig. 316. These figures represent the rectangular coordinates for hole No. 8.

Note that the dimensions in the tables are shown from the left hand and upper tangents of circles. Adding is more convenient for most people than subtraction.

It is necessary, of course, to keep the angular orientation of the divided circle in mind. Hole No. 1 must be the first hole counter-clockwise from the vertical center line.

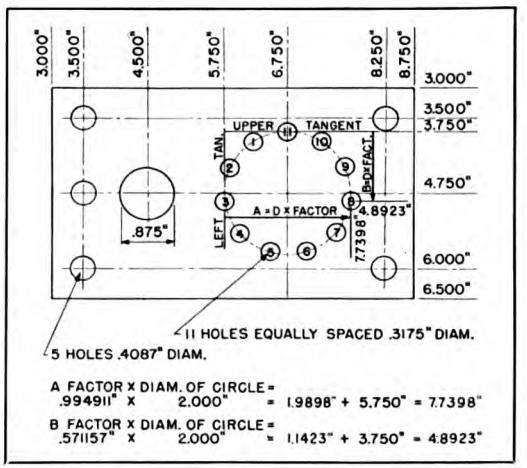
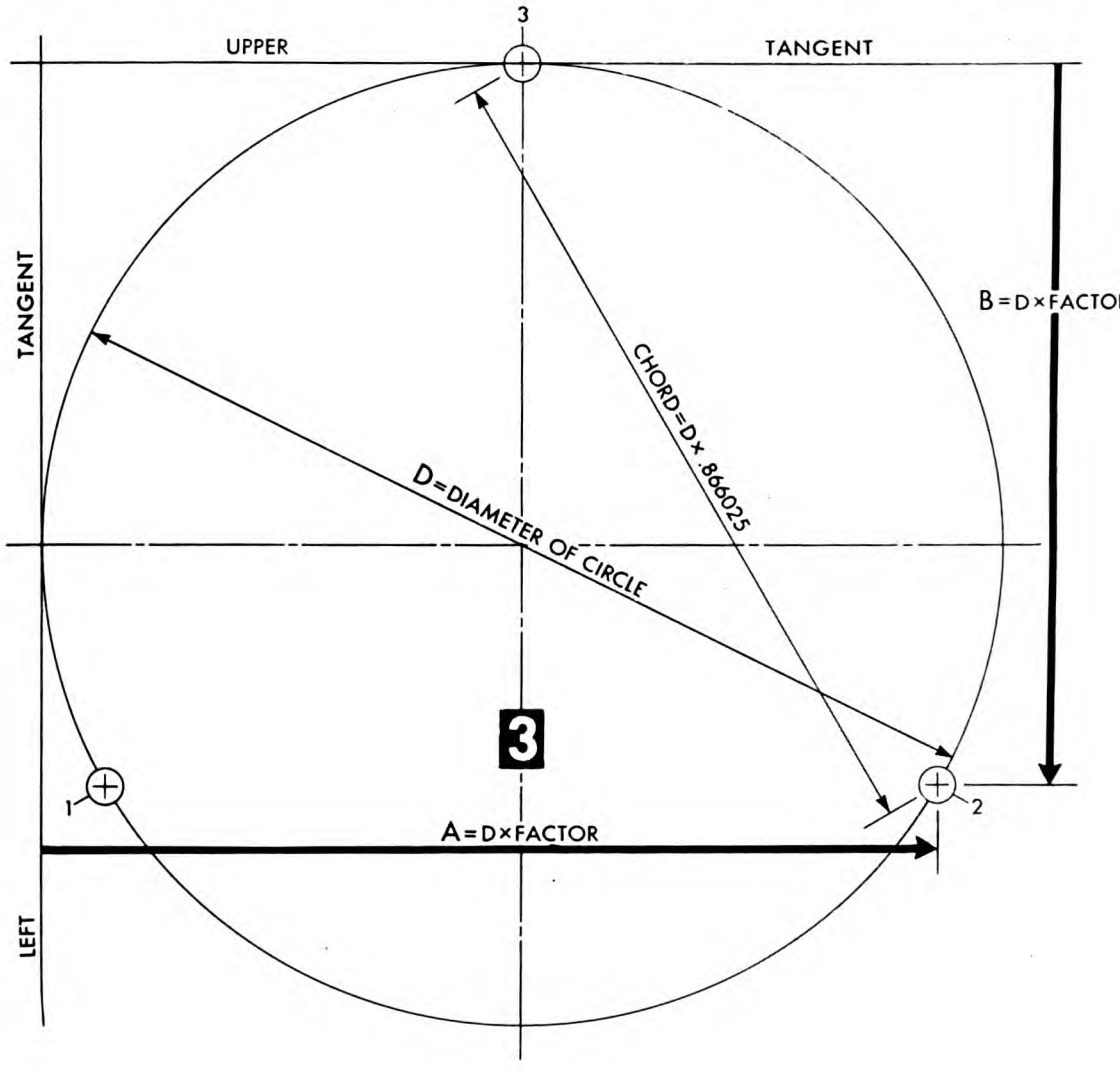


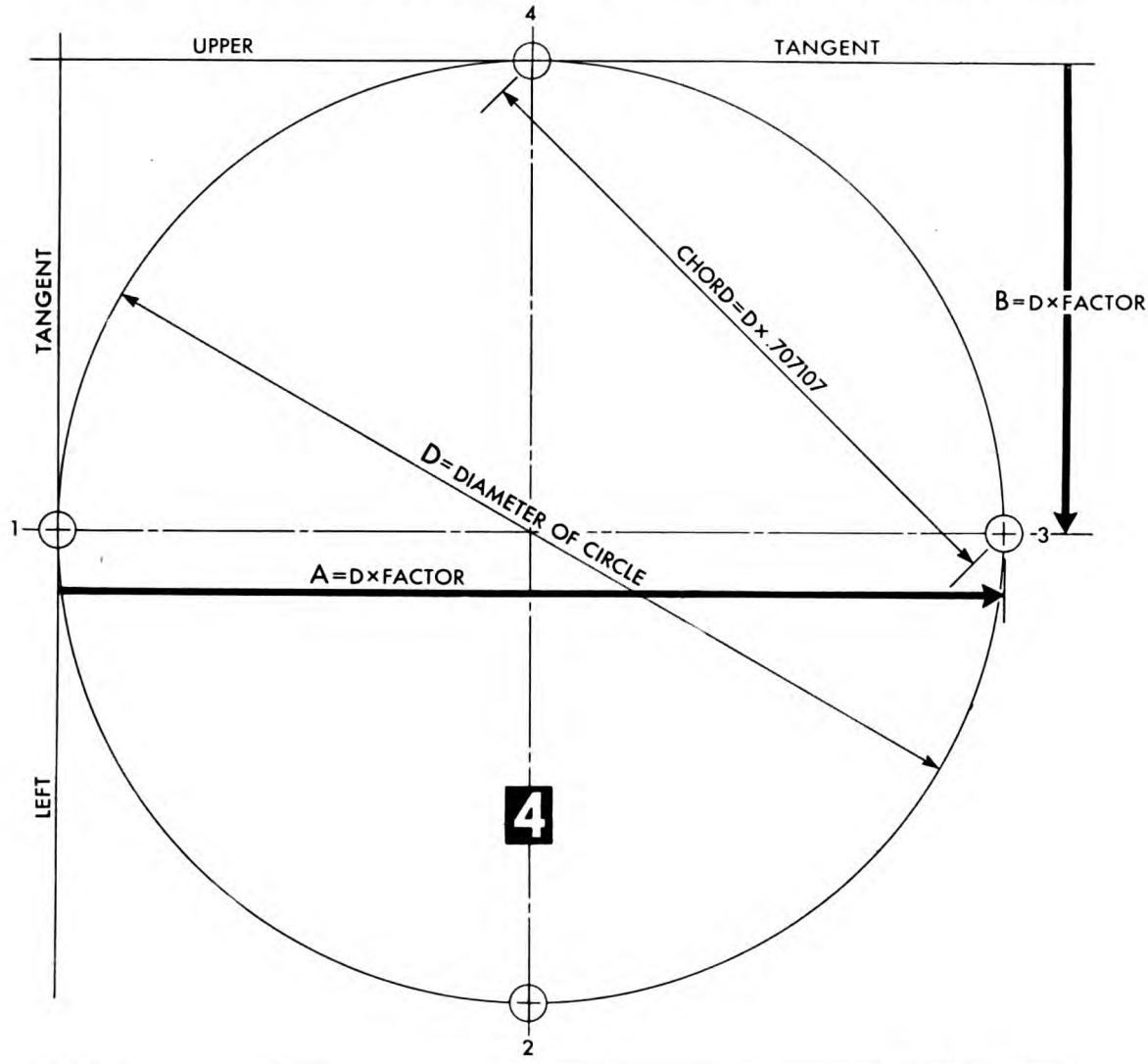
Fig. 316 — The procedure, as here illustrated for hole No. 8, is followed for all remaining holes on the circle.

3 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



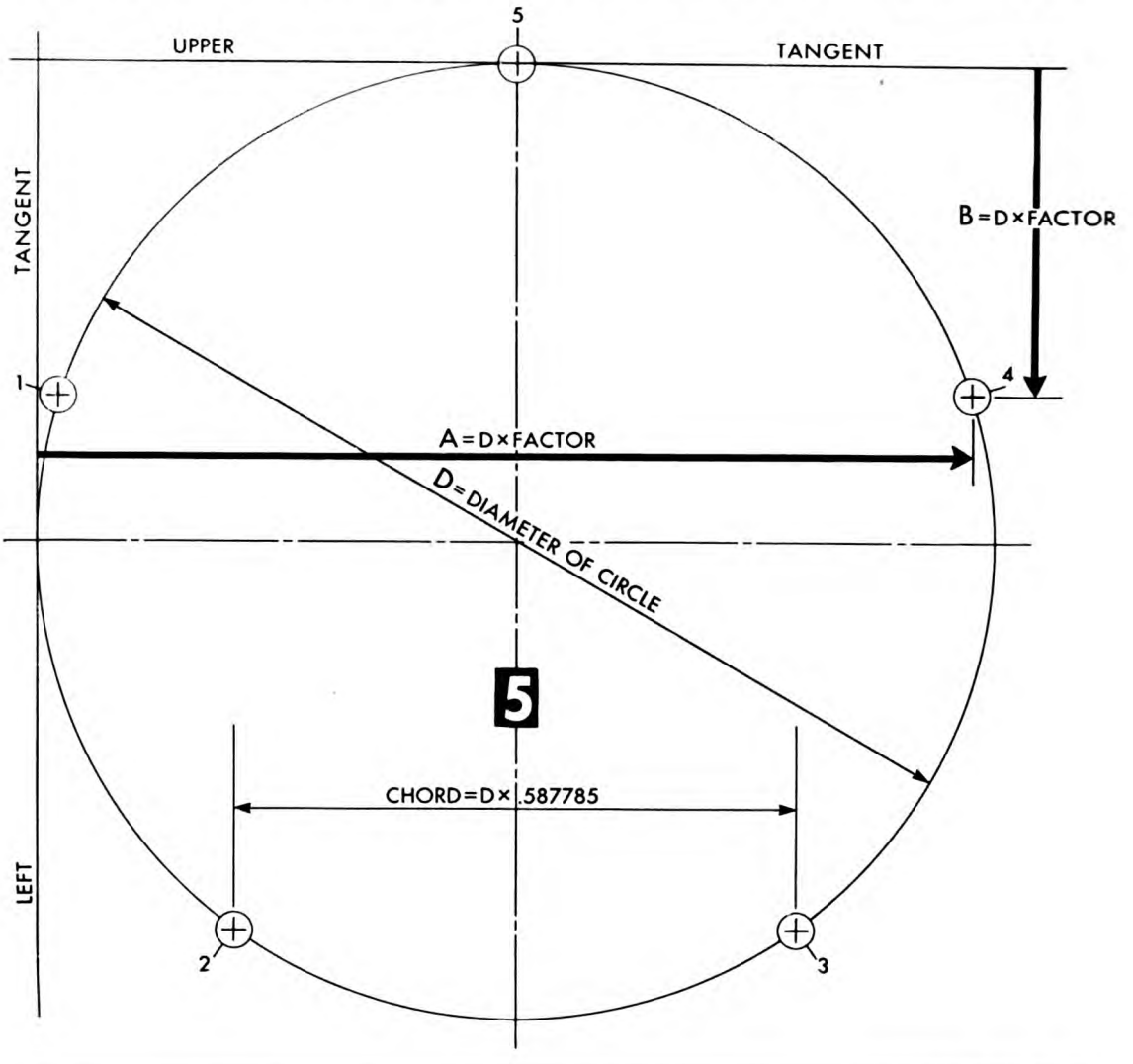
→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.066987	1	.750000	1	120	0	0
2	.933013	2	.750000	2	240	0	0
3	.500000	3	.000000	3	360	0	0

COORDINATE FACTORS AND ANGLES—4 HOLE DIVISION



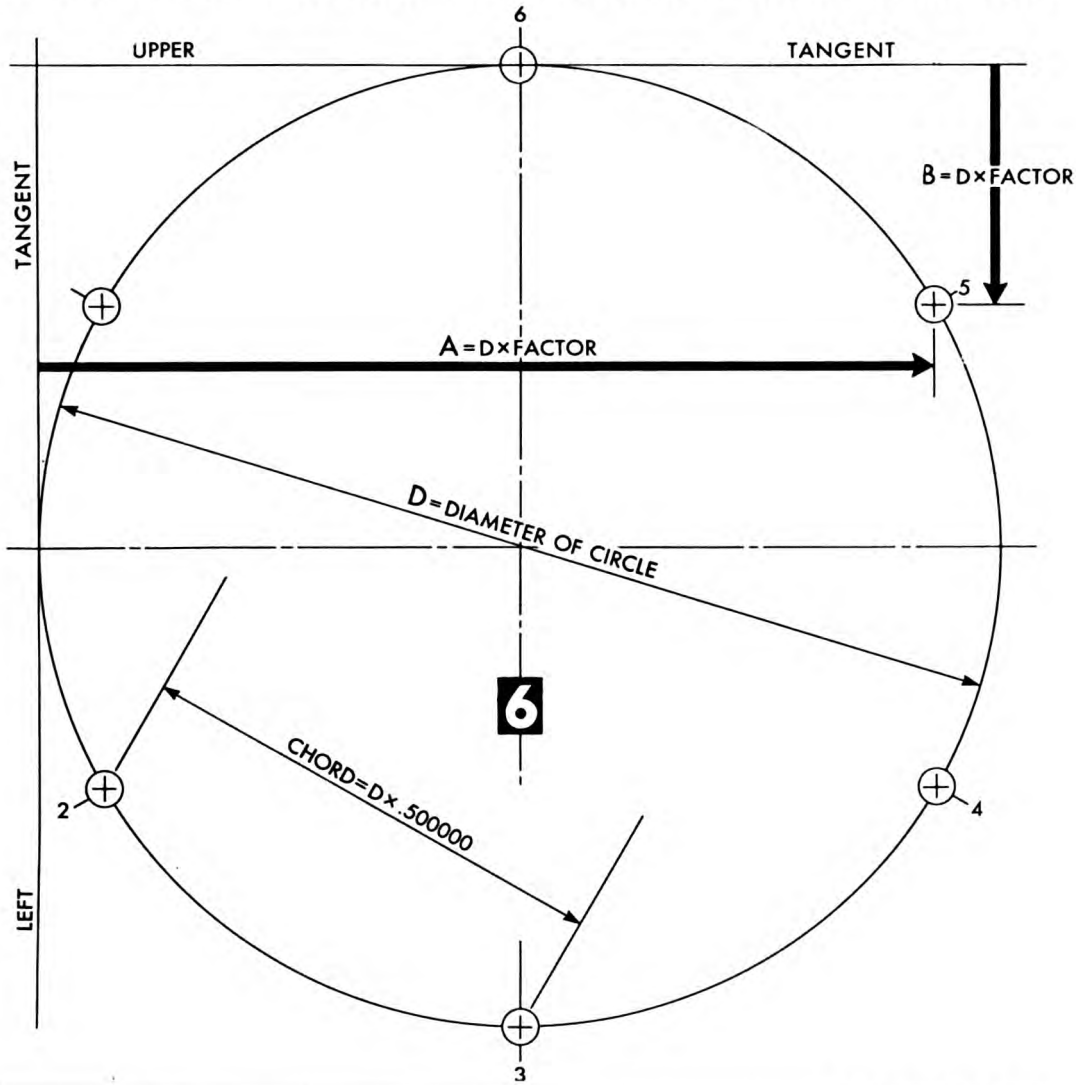
	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.000000	1	.500000	1	90	0	0
2	.500000	2	1.000000	2	180	0	0
3	1.000000	3	.500000	3	270	0	0
4	.500000	4	.000000	4	360	0	0

5 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



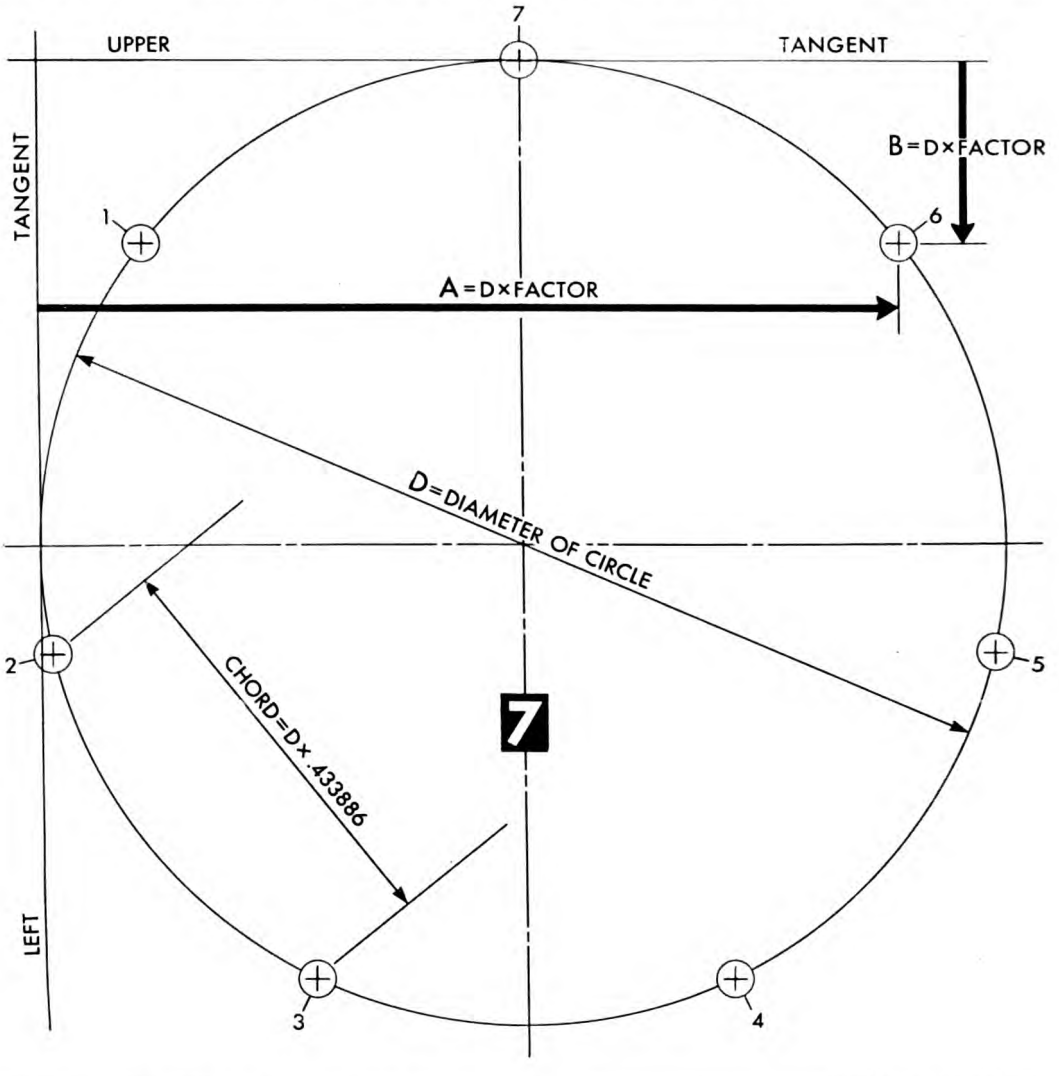
	➡ FACTOR FOR "A"	FACTOR FOR "B" ⬇		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.024472	1	.345492	1	72	0	0
2	.206107	2	.904508	2	144	0	0
3	.793893	3	.904508	3	216	0	0
4	.975528	4	.345492	4	288	0	0
5	.500000	5	.000000	5	360	0	0

COORDINATE FACTORS AND ANGLES—6 HOLE DIVISION



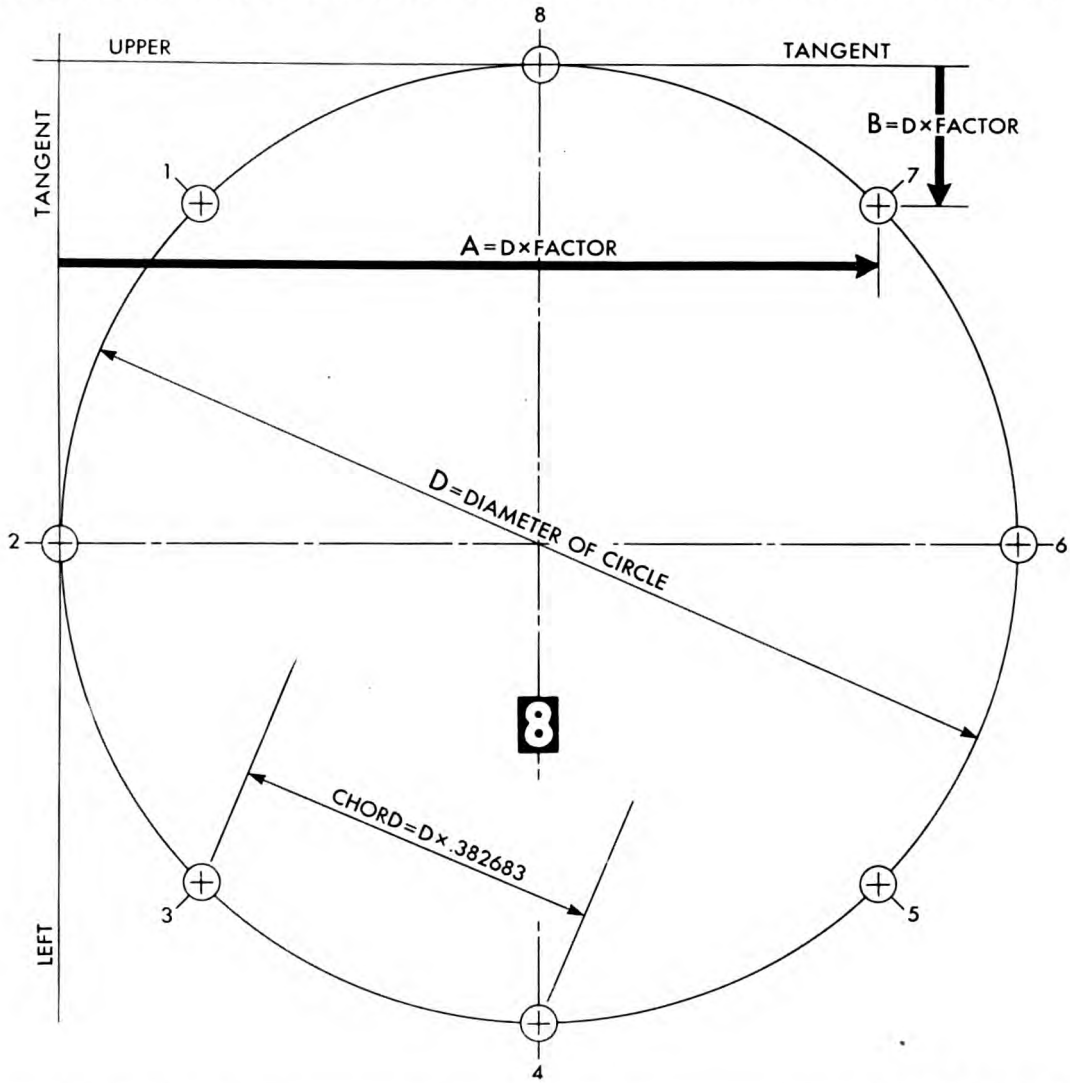
	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.066987	1	.250000	1	60	0	0
2	.066987	2	.750000	2	120	0	0
3	.500000	3	1.000000	3	180	0	0
4	.933013	4	.750000	4	240	0	0
5	.933013	5	.250000	5	300	0	0
6	.500000	6	.000000	6	360	0	0

7 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



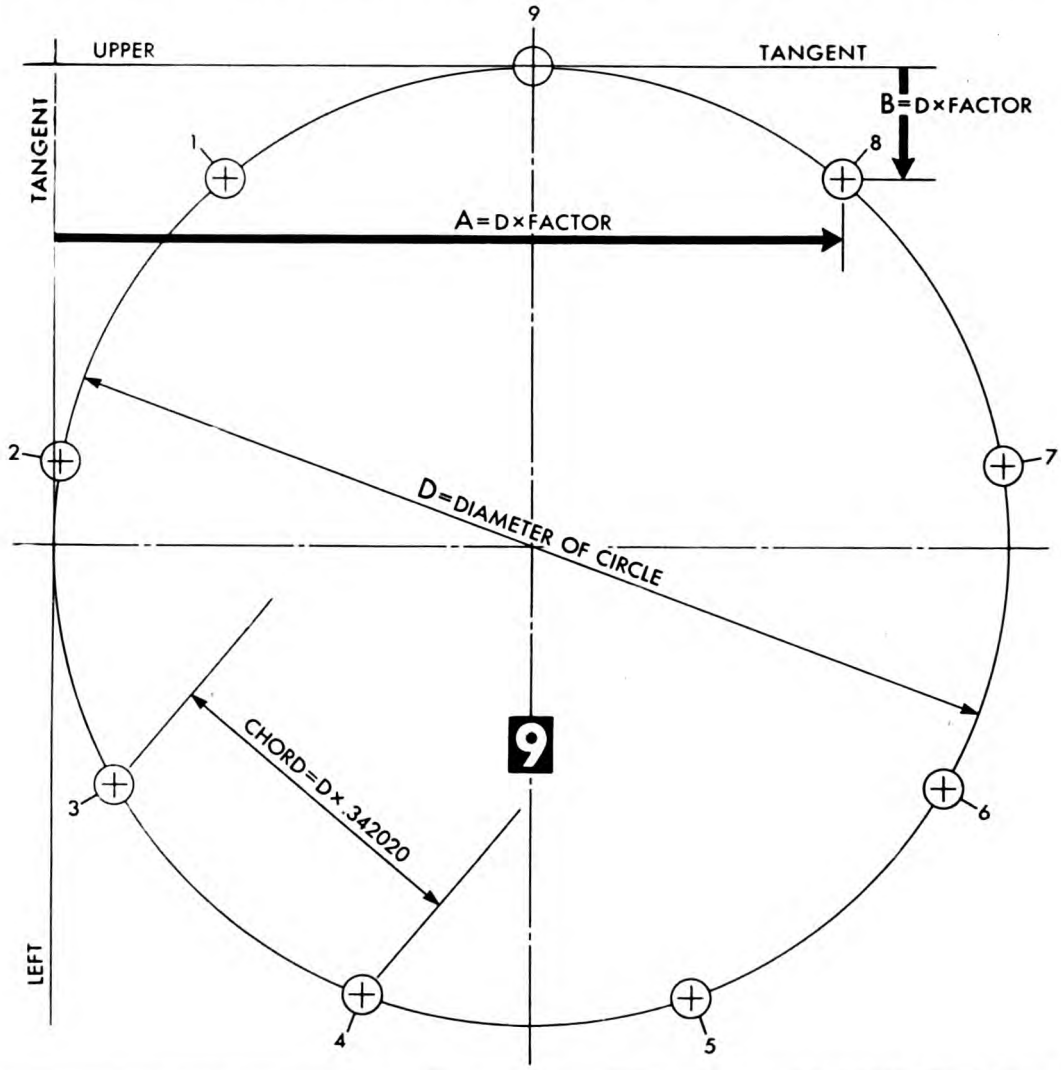
→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.109084	1	.188255	1	51	25	42-6/7
2	.012536	2	.611261	2	102	51	23-5/7
3	.283058	3	.950484	3	154	17	8-4/7
4	.716942	4	.950484	4	205	42	51-3/7
5	.987464	5	.611261	5	257	8	34-2/7
6	.890916	6	.188255	6	308	34	17-1/7
7	.500000	7	.000000	7	360	0	0

COORDINATE FACTORS AND ANGLES—8 HOLE DIVISION



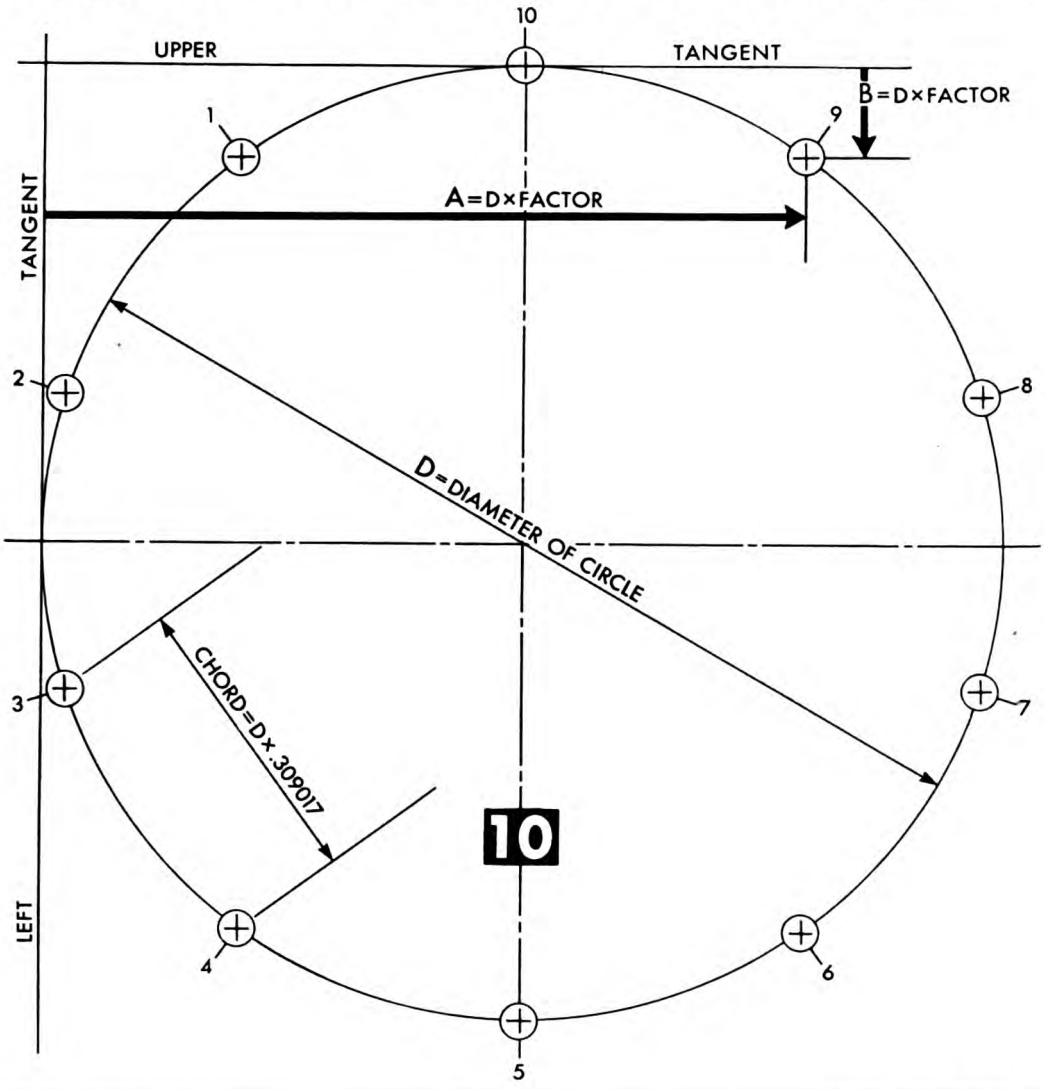
	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.146447	1	.146447	1	45	0	0
2	.000000	2	.500000	2	90	0	0
3	.146447	3	.853553	3	135	0	0
4	.500000	4	1.000000	4	180	0	0
5	.853553	5	.853553	5	225	0	0
6	1.000000	6	.500000	6	270	0	0
7	.853553	7	.146447	7	315	0	0
8	.500000	8	.000000	8	360	0	0

9 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



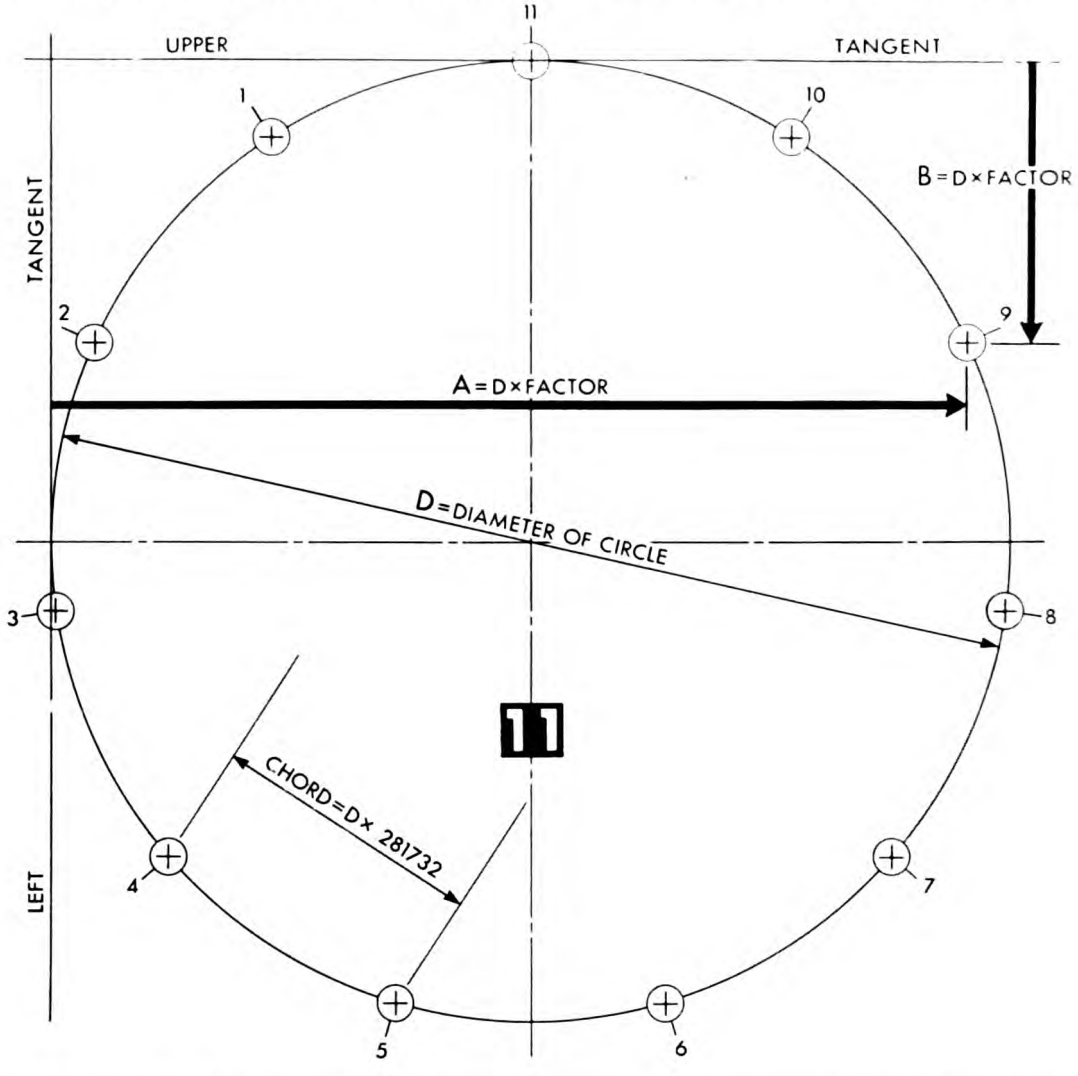
→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.178606	1	.116978	1	40	0	0
2	.007596	2	.413176	2	80	0	0
3	.066987	3	.750000	3	120	0	0
4	.328990	4	.969846	4	160	0	0
5	.671010	5	.969846	5	200	0	0
6	.933013	6	.750000	6	240	0	0
7	.992404	7	.413176	7	280	0	0
8	.821394	8	.116978	8	320	0	0
9	.500000	9	.000000	9	360	0	0

COORDINATE FACTORS AND ANGLES—10 HOLE DIVISION



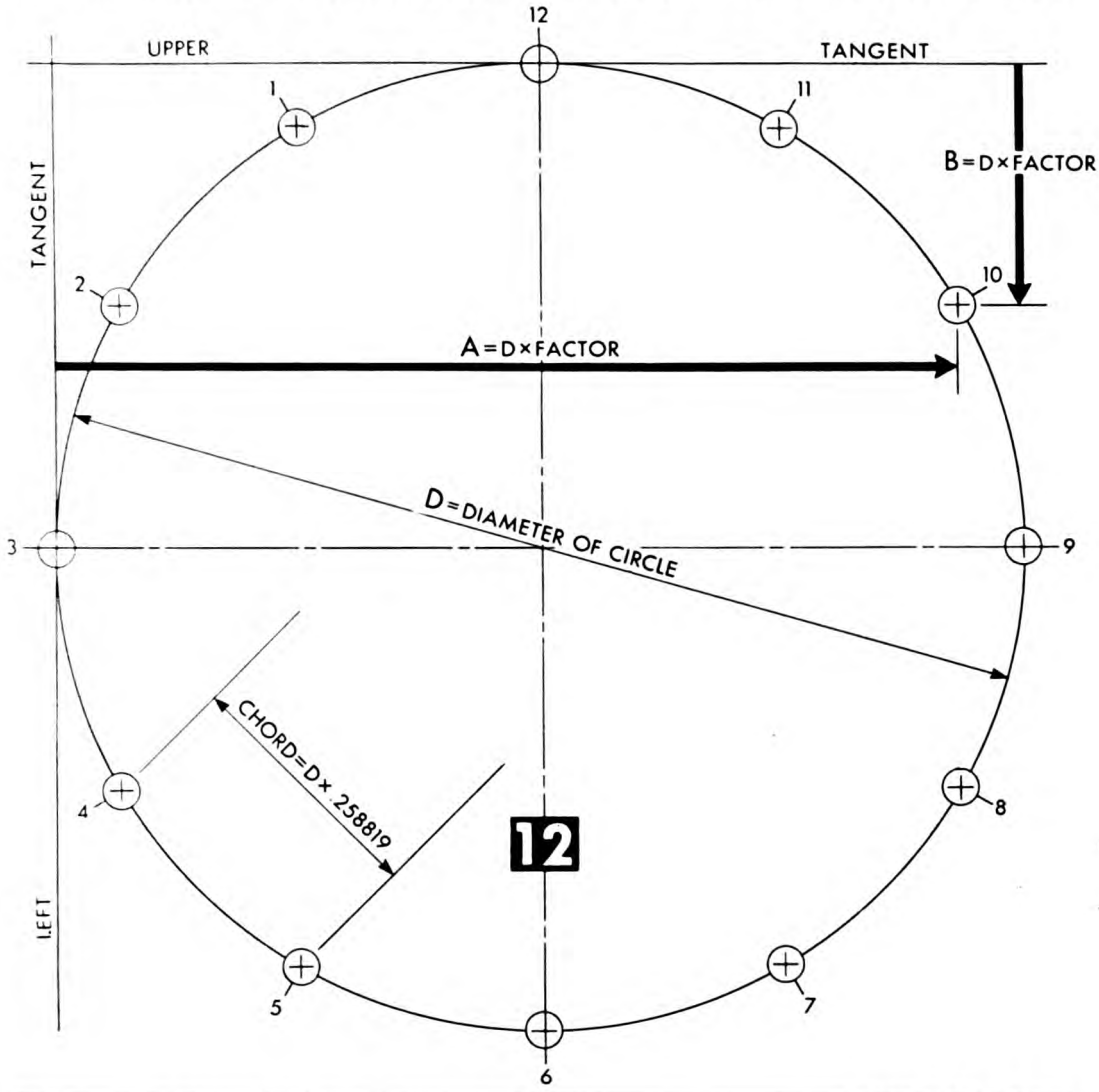
→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.206107	1	.095492	1	36	0	0
2	.024472	2	.345492	2	72	0	0
3	.024472	3	.654508	3	108	0	0
4	.206107	4	.904508	4	144	0	0
5	.500000	5	1.000000	5	180	0	0
6	.793893	6	.904508	6	216	0	0
7	.975528	7	.654508	7	252	0	0
8	.975528	8	.345492	8	288	0	0
9	.793893	9	.095492	9	324	0	0
10	.500000	10	.000000	10	360	0	0

11 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



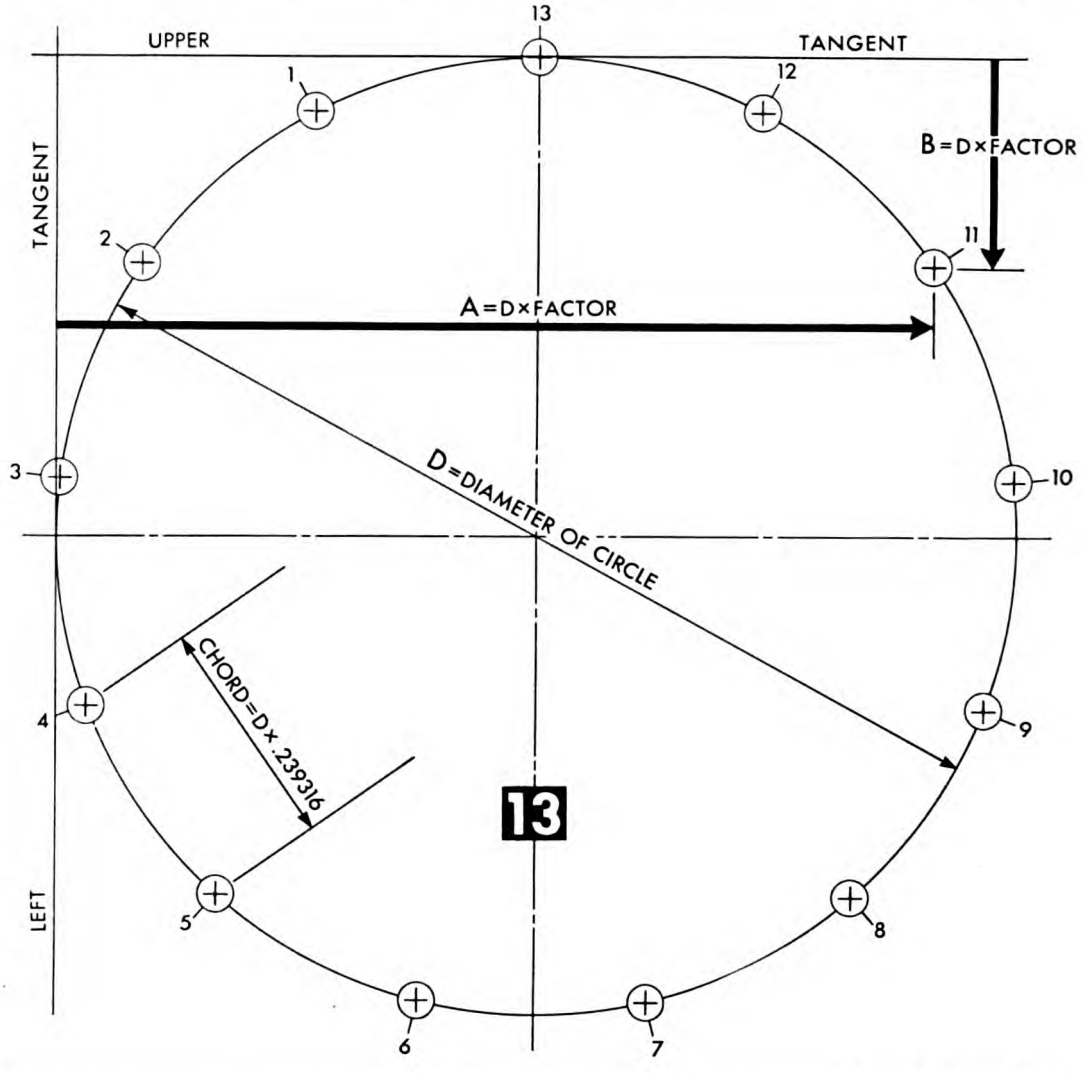
→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.229680	1	.079373	1	32	43 38- 2/11
2	.045184	2	.292293	2	65	27 16- 4/11
3	.005089	3	.571157	3	98	10 54- 6/11
4	.122125	4	.827430	4	130	54 32- 8/11
5	.359134	5	.979746	5	163	38 10-10/11
6	.640866	6	.979746	6	196	21 49- 1/11
7	.877875	7	.827430	7	229	5 27- 3/11
8	.994911	8	.571157	8	261	49 5- 5/11
9	.954816	9	.292293	9	294	32 43- 7/11
10	.770320	10	.079373	10	327	16 21- 9/11
11	.500000	11	.000000	11	360	0 0

COORDINATE FACTORS AND ANGLES—12 HOLE DIVISION



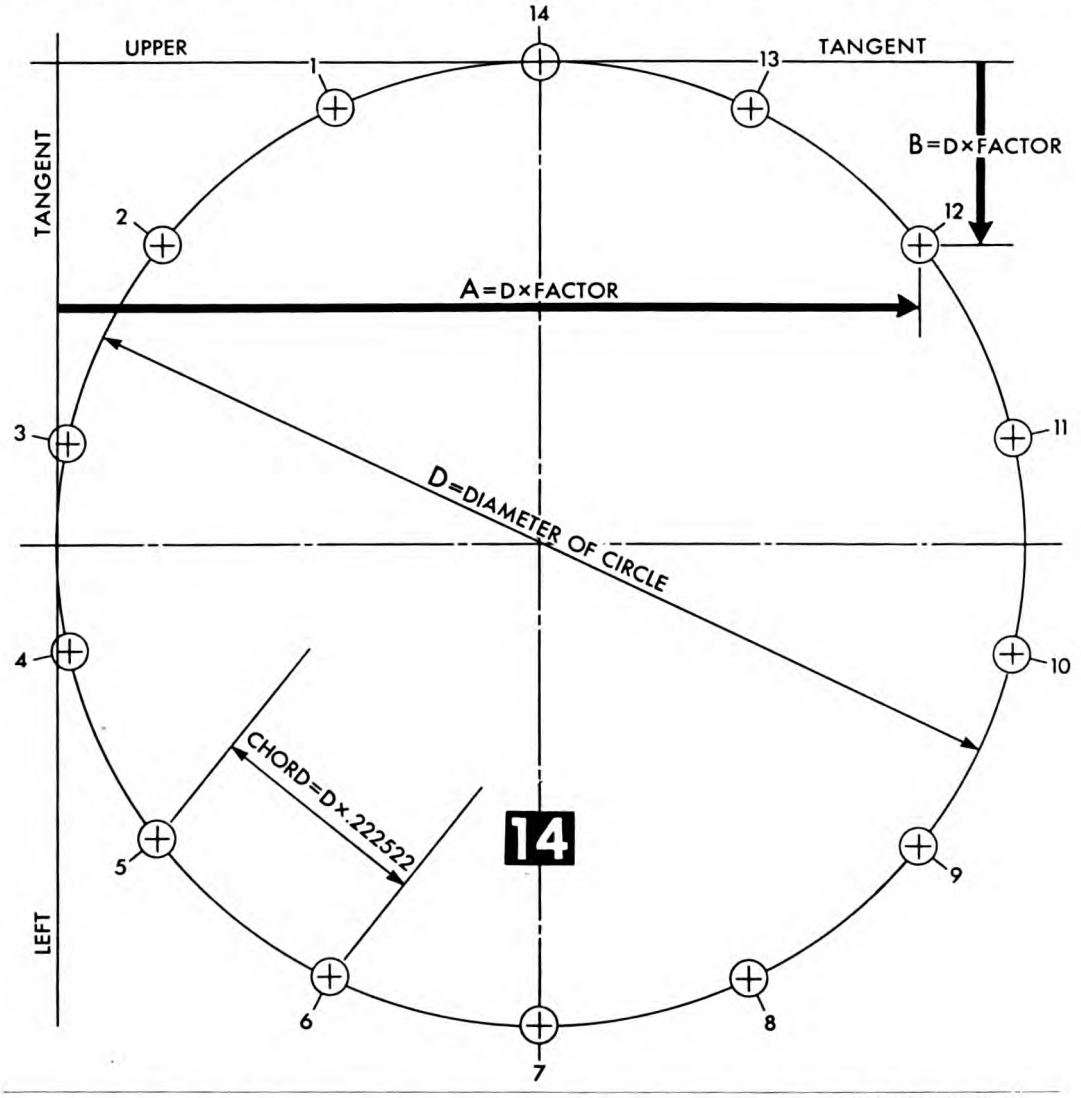
→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.250000	1	.066987	1	30	0	0
2	.066987	2	.250000	2	60	0	0
3	.000000	3	.500000	3	90	0	0
4	.066987	4	.750000	4	120	0	0
5	.250000	5	.933013	5	150	0	0
6	.500000	6	1.000000	6	180	0	0
7	.750000	7	.933013	7	210	0	0
8	.933013	8	.750000	8	240	0	0
9	1.000000	9	.500000	9	270	0	0
10	.933013	10	.250000	10	300	0	0
11	.750000	11	.066987	11	330	0	0
12	.500000	12	.000000	12	360	0	0

13 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



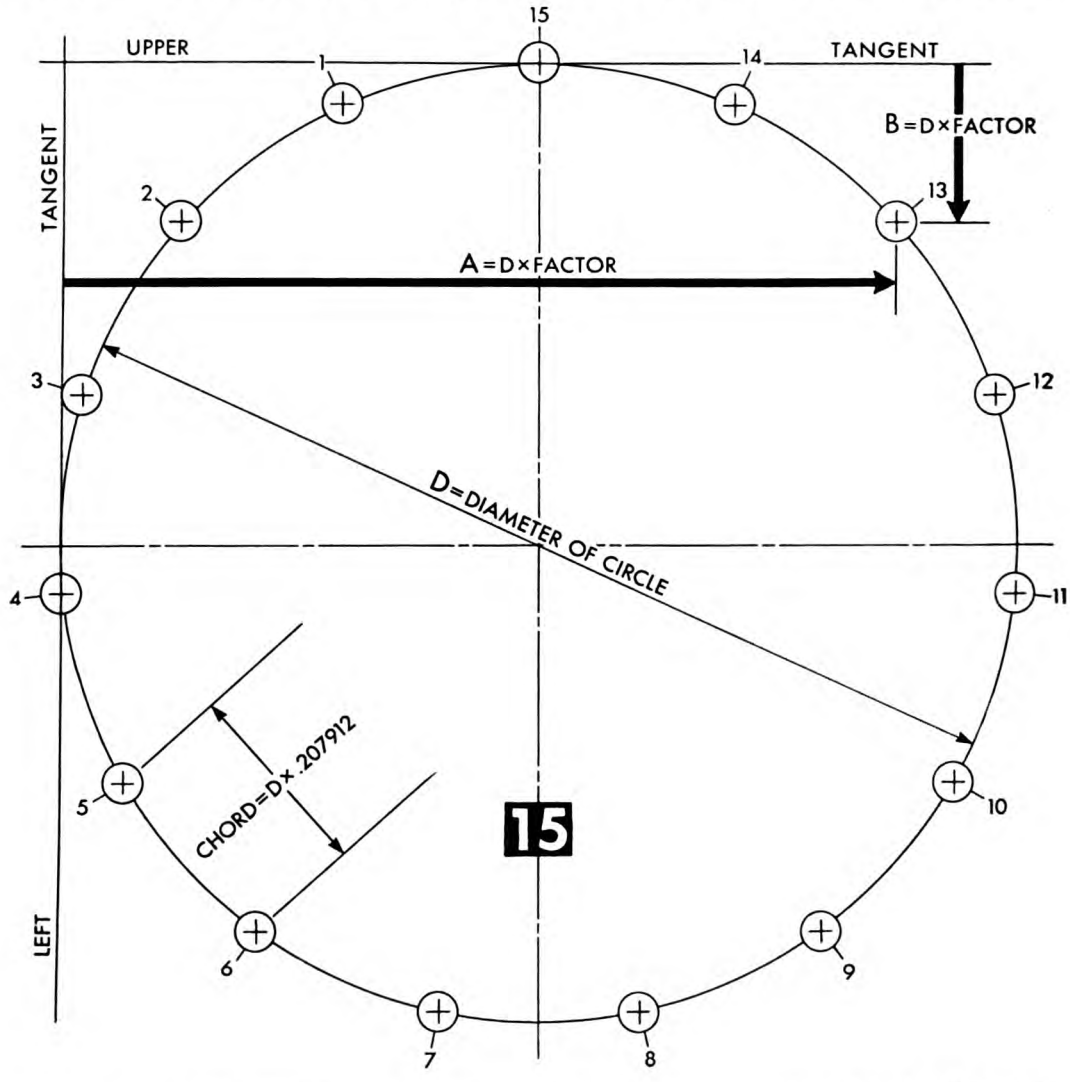
➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.267638	1	.057272	1	27	41 32- 4/13
2	.088508	2	.215968	2	55	23 4- 8/13
3	.003646	3	.439732	3	83	4 36-12/13
4	.032492	4	.677302	4	110	46 9- 3/13
5	.168439	5	.874255	5	138	27 41- 7/13
6	.380342	6	.985471	6	166	9 13-11/13
7	.619658	7	.985471	7	193	50 46- 2/13
8	.831561	8	.874255	8	221	32 18- 6/13
9	.967508	9	.677302	9	249	13 50-10/13
10	.996354	10	.439732	10	276	55 23- 1/13
11	.911492	11	.215968	11	304	36 55- 5/13
12	.732362	12	.057272	12	332	18 27- 9/13
13	.500000	13	.000000	13	360	0 0

COORDINATE FACTORS AND ANGLES—14 HOLE DIVISION



→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.283058	1	.049516	1	25	42	51- 6/14
2	.109084	2	.188255	2	51	25	42-12/14
3	.012536	3	.388740	3	77	8	34- 4/14
4	.012536	4	.611261	4	102	51	25-10/14
5	.109084	5	.811745	5	128	34	17- 2/14
6	.283058	6	.950484	6	154	17	8- 8/14
7	.500000	7	1.000000	7	180	00	00000000
8	.716942	8	.950484	8	205	42	51- 6/14
9	.890916	9	.811745	9	231	25	42-12/14
10	.987464	10	.611261	10	257	8	34- 4/14
11	.987464	11	.388740	11	282	51	25-10/14
12	.890916	12	.188255	12	308	34	17- 2/14
13	.716942	13	.049516	13	334	17	8- 8/14
14	.500000	14	.000000	14	360	0	0

15 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

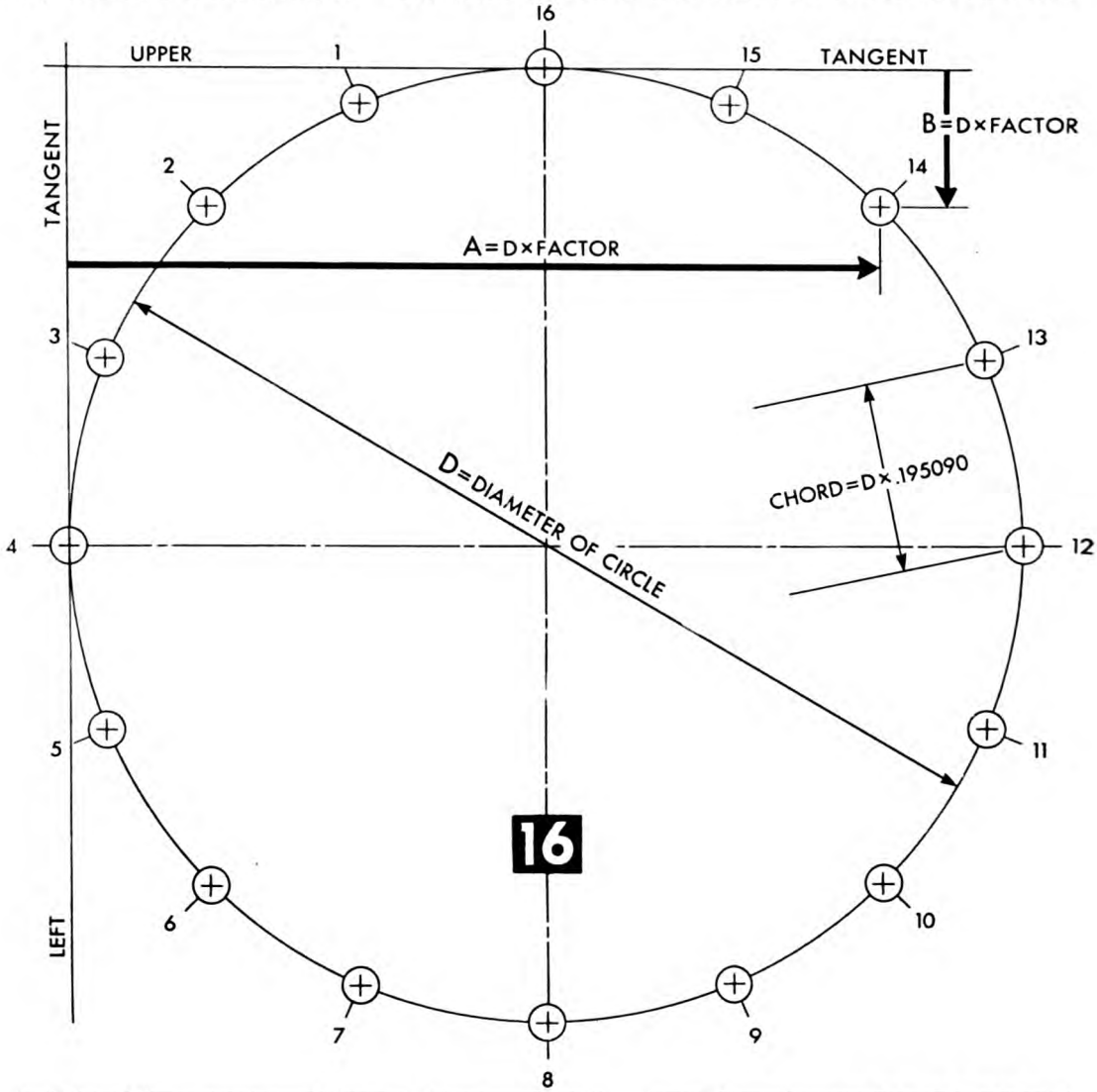


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.296632	1	.043227	1	24	0	0
2	.128428	2	.165435	2	48	0	0
3	.024472	3	.345492	3	72	0	0
4	.002739	4	.552264	4	96	0	0
5	.066987	5	.750000	5	120	0	0
6	.206107	6	.904509	6	144	0	0
7	.396044	7	.989074	7	168	0	0
8	.603956	8	.989074	8	192	0	0
9	.793893	9	.904509	9	216	0	0
10	.933013	10	.750000	10	240	0	0

COORDINATE FACTORS AND ANGLES—15 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.997261	11	.552264	11	264	0	0
12	.975528	12	.345492	12	288	0	0
13	.871572	13	.165435	13	312	0	0
14	.703368	14	.043227	14	336	0	0
15	.500000	15	.000000	15	360	0	0

16 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

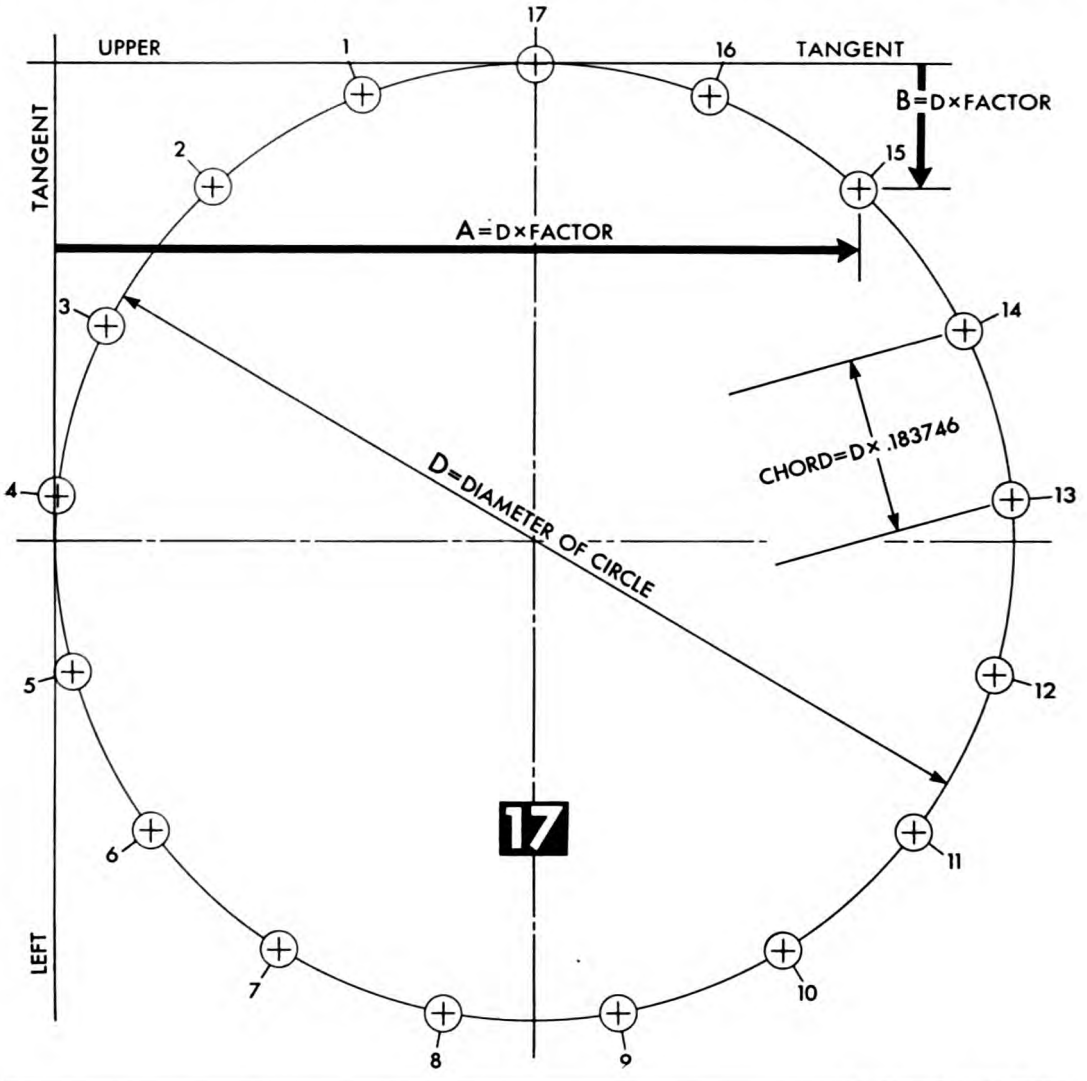


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.308658	1	.038060	1	22	30	0
2	.146447	2	.146447	2	45	00	0
3	.038060	3	.308658	3	67	30	0
4	.000000	4	.500000	4	90	00	0
5	.038060	5	.691342	5	112	30	0
6	.146447	6	.853553	6	135	00	0
7	.308658	7	.961940	7	157	30	0
8	.500000	8	1.000000	8	180	00	0
9	.691342	9	.961940	9	202	30	0
10	.853553	10	.853553	10	225	00	0

COORDINATE FACTORS AND ANGLES—16 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.961940	11	.691342	11	247	30	0
12	1.000000	12	.500000	12	270	00	0
13	.961940	13	.308658	13	292	30	0
14	.853553	14	.146447	14	315	00	0
15	.691342	15	.038060	15	337	30	0
16	.500000	16	.000000	16	360	0	0

17 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

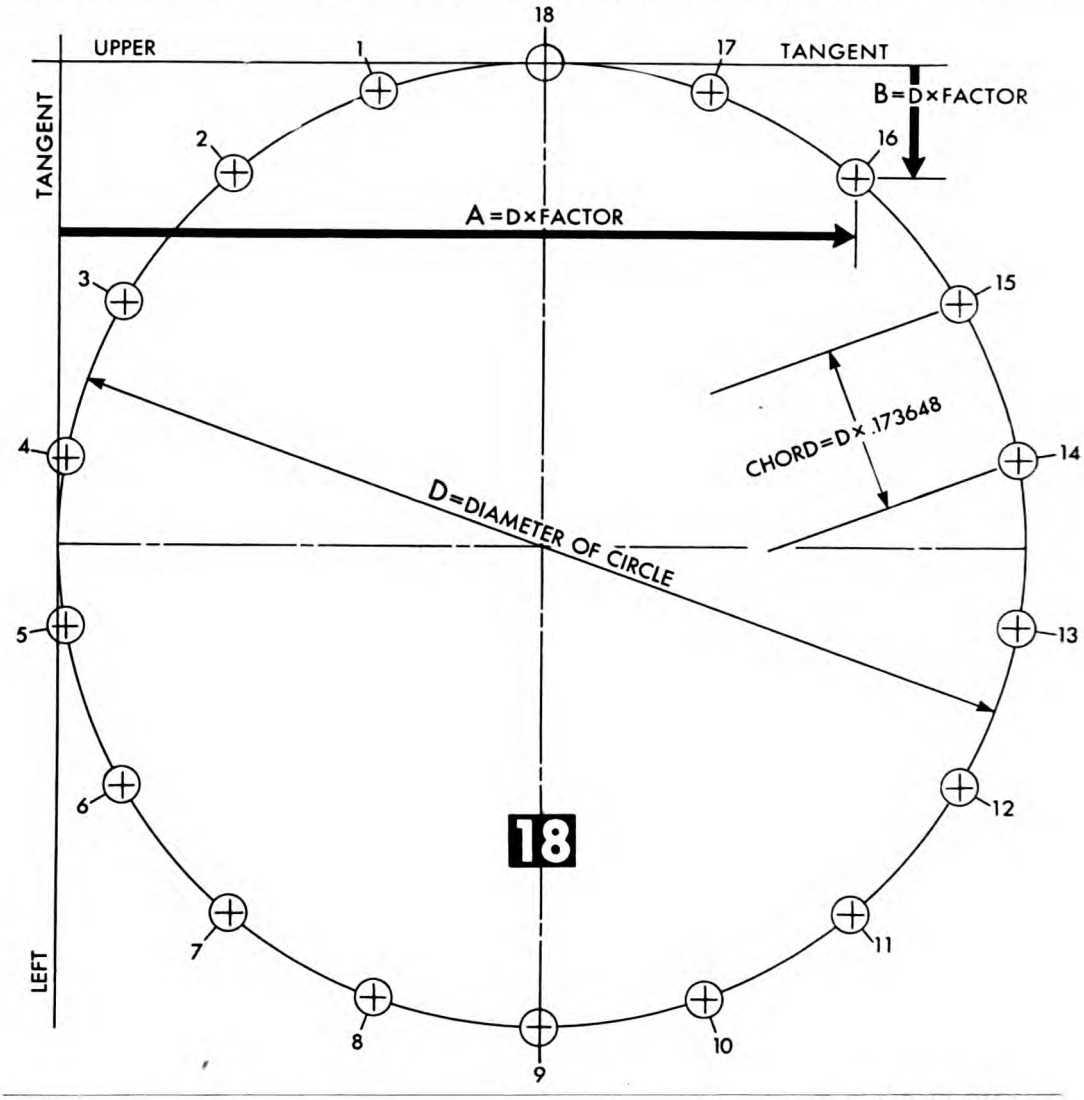


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.319379	1	.033764	1	21	10 35- 5/17
2	.163152	2	.130496	2	42	21 10-10/17
3	.052418	3	.277131	3	63	31 45-15/17
4	.002133	4	.453866	4	84	42 21- 3/17
5	.019087	5	.636832	5	105	52 56- 8/17
6	.100991	6	.801317	6	127	3 31-13/17
7	.236784	7	.925109	7	148	14 7- 1/17
8	.408125	8	.991487	8	169	24 42- 6/17
9	.591875	9	.991487	9	190	35 17-11/17
10	.763216	10	.925109	10	211	45 52-16/17

COORDINATE FACTORS AND ANGLES—17 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.899009	11	.801317	11	232	56 28– 4/17
12	.980913	12	.636832	12	254	7 3– 9/17
13	.997867	13	.453866	13	275	17 38–14/17
14	.947582	14	.277131	14	296	28 14– 2/17
15	.836848	15	.130496	15	317	38 49– 7/17
16	.680621	16	.033764	16	338	49 24–12/17
17	.500000	17	.000000	17	360	0 0

18 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

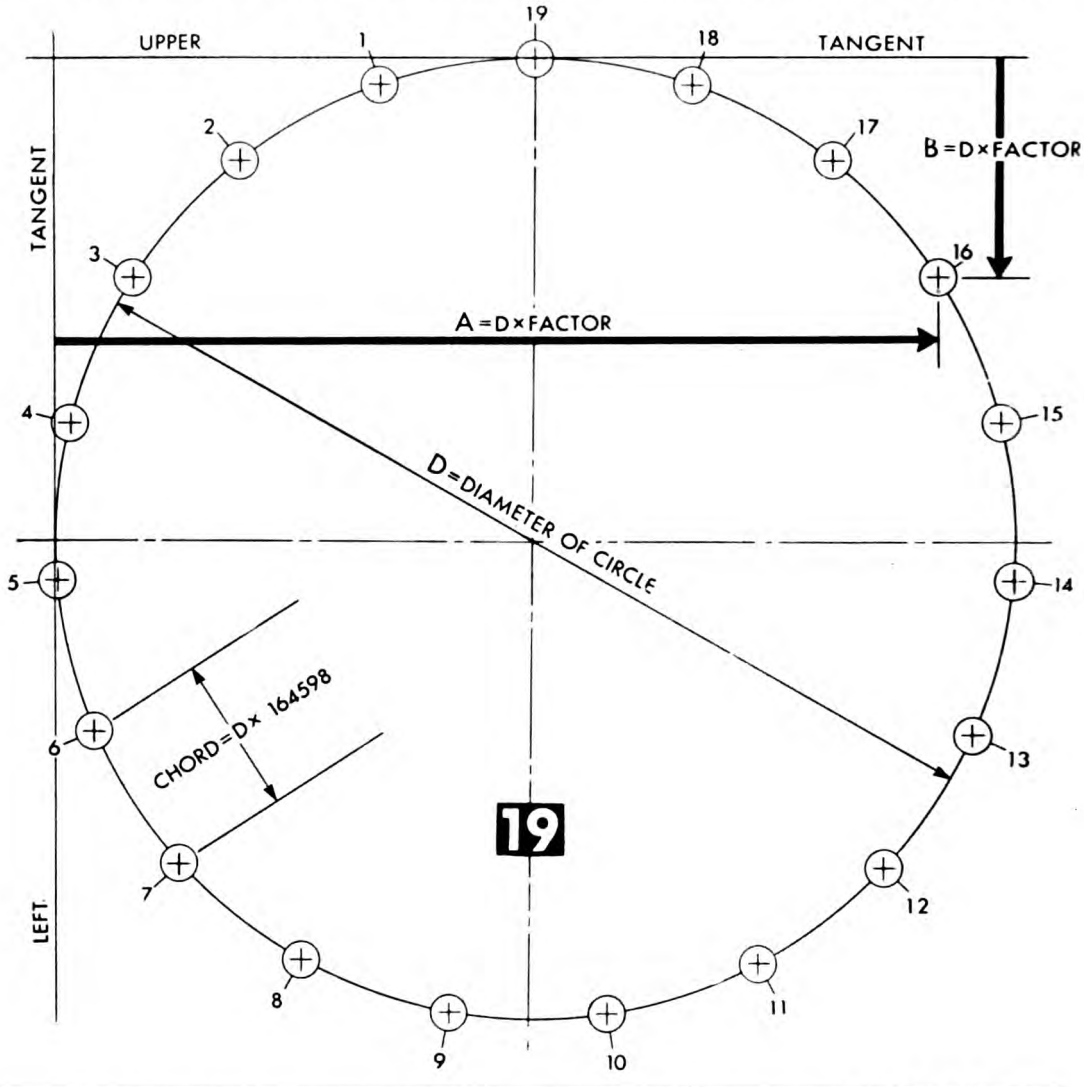


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.328990	1	.030154	1	20	0	0
2	.178606	2	.116978	2	40	0	0
3	.066987	3	.250000	3	60	0	0
4	.007596	4	.413176	4	80	0	0
5	.007596	5	.586824	5	100	0	0
6	.066987	6	.750000	6	120	0	0
7	.178606	7	.883022	7	140	0	0
8	.328990	8	.969846	8	160	0	0
9	.500000	9	1.000000	9	180	0	0
10	.671010	10	.969846	10	200	0	0

COORDINATE FACTORS AND ANGLES—18 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.821394	11	.883022	11	220	0	0
12	.933013	12	.750000	12	240	0	0
13	.992404	13	.586824	13	260	0	0
14	.992404	14	.413176	14	280	0	0
15	.933013	15	.250000	15	300	0	0
16	.821394	16	.116978	16	320	0	0
17	.671010	17	.030154	17	340	0	0
18	.500000	18	.000000	18	360	0	0

19 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

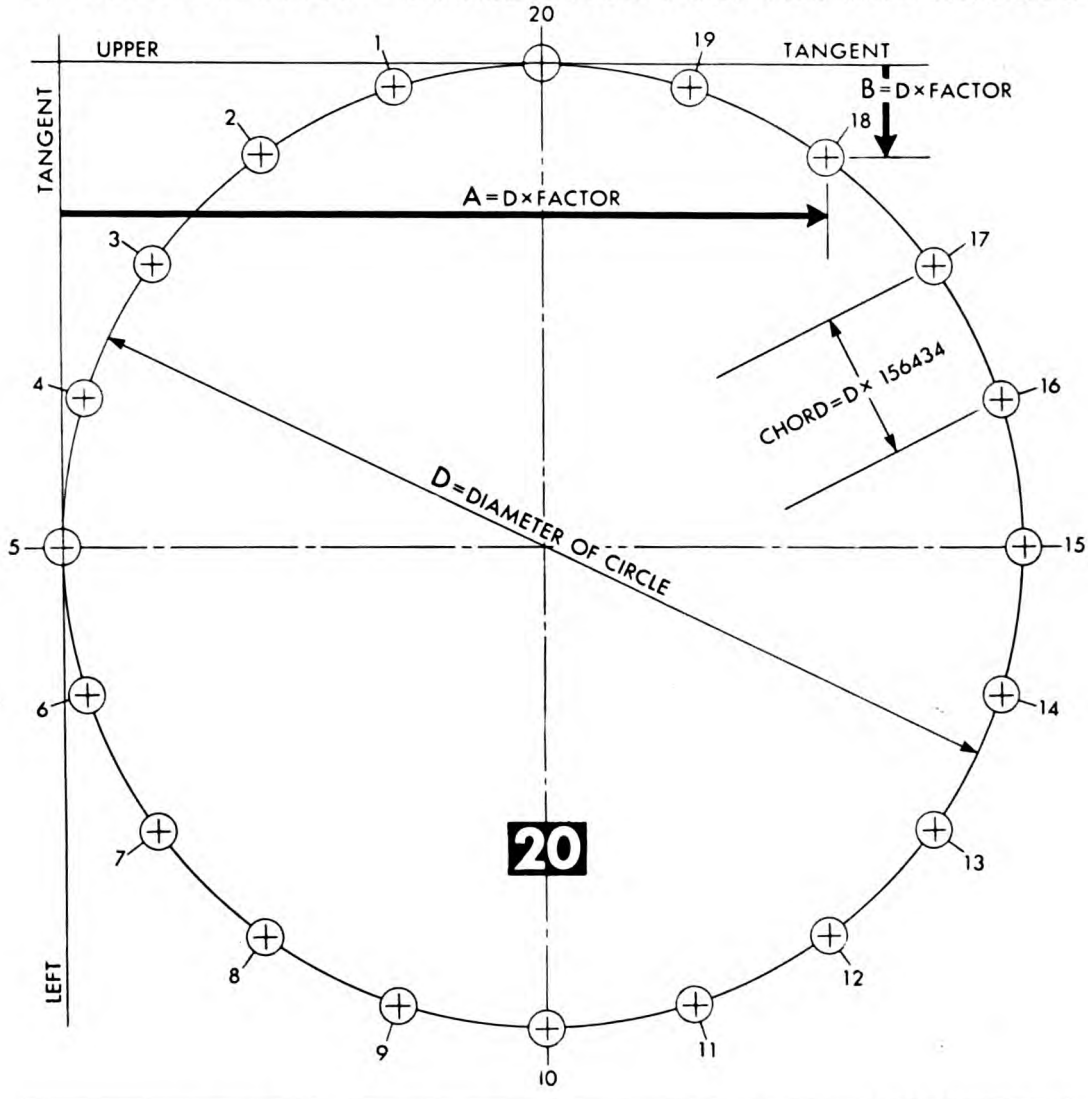


	FACTOR FOR "A"	FACTOR FOR "B"		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.337650	1	.027091	1	18	56 50–10/19
2	.192894	2	.105430	2	37	53 41– 1/19
3	.081417	3	.226526	3	56	50 31–11/19
4	.015300	4	.377257	4	75	47 22– 2/19
5	.001708	5	.541290	5	94	44 12–12/19
6	.042113	6	.700848	6	113	41 3– 3/19
7	.132138	7	.838641	7	132	37 53–13/19
8	.262026	8	.939737	8	151	34 44– 4/19
9	.417703	9	.993181	9	170	31 34–14/19
10	.582297	10	.993181	10	189	28 25– 5/19

COORDINATE FACTORS AND ANGLES—19 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.737974	11	.939737	11	208	25 15-15/19
12	.867862	12	.838641	12	227	22 6- 6/19
13	.957887	13	.700848	13	246	18 56-16/19
14	.998292	14	.541290	14	265	15 47- 7/19
15	.984700	15	.377257	15	284	12 37-17/19
16	.918583	16	.226526	16	303	9 28- 8/19
17	.807106	17	.105430	17	322	6 18-18/19
18	.662350	18	.027091	18	341	3 9- 9/19
19	.500000	19	.000000	19	360	0 0

20 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

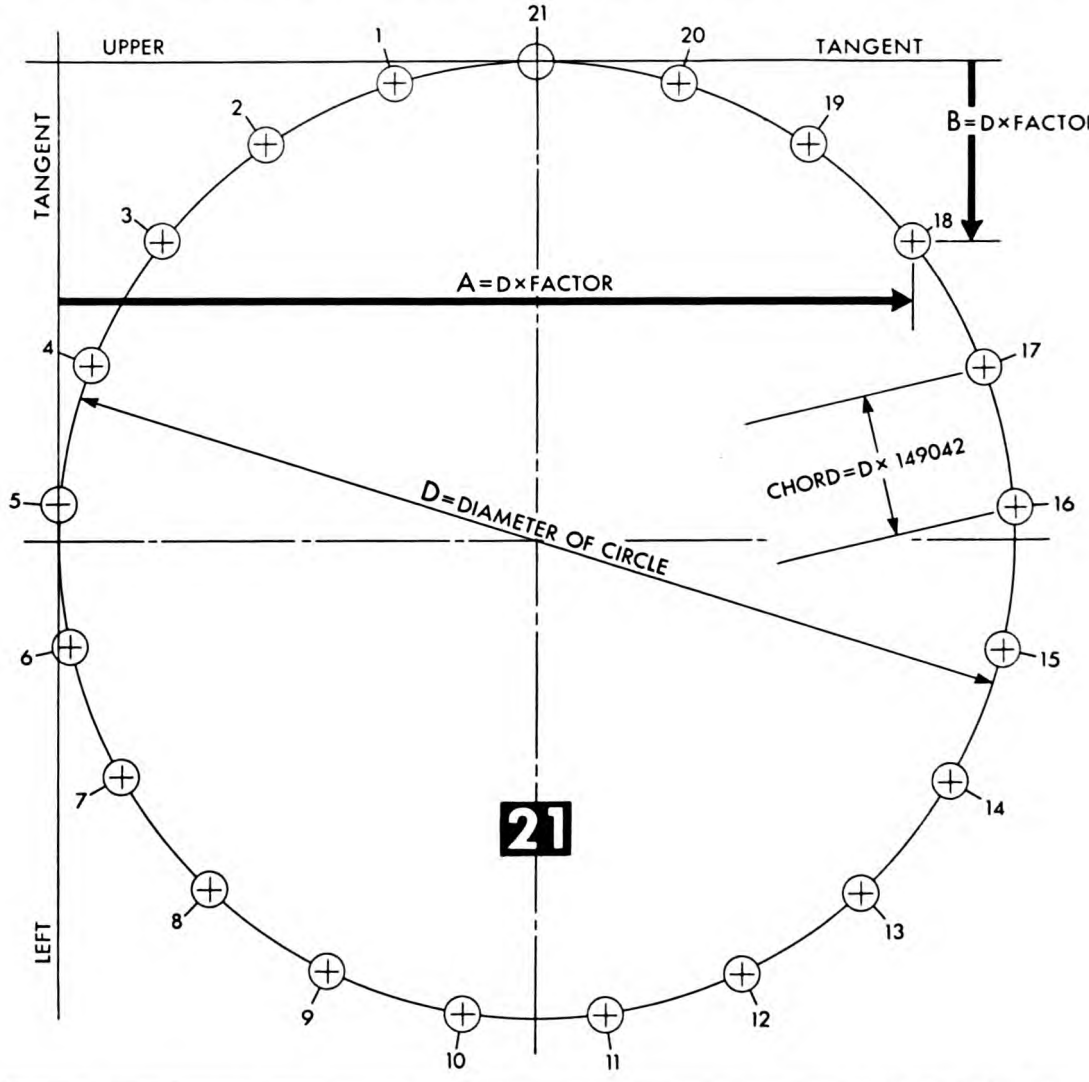


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.345492	1	.024472	1	18	0	0
2	.206107	2	.095492	2	36	0	0
3	.095492	3	.206107	3	54	0	0
4	.024472	4	.345492	4	72	0	0
5	.000000	5	.500000	5	90	0	0
6	.024472	6	.654508	6	108	0	0
7	.095492	7	.793893	7	126	0	0
8	.206107	8	.904508	8	144	0	0
9	.345492	9	.975528	9	162	0	0
10	.500000	10	1.000000	10	180	0	0

COORDINATE FACTORS AND ANGLES—20 HOLE DIVISION

	FACTOR FOR "A"	FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓	DEG.	MIN.	SEC.
11	.654508	11	.975528	11	198	0	0
12	.793893	12	.904508	12	216	0	0
13	.904508	13	.793893	13	234	0	0
14	.975528	14	.654508	14	252	0	0
15	1.000000	15	.500000	15	270	0	0
16	.975528	16	.345492	16	288	0	0
17	.904508	17	.206107	17	306	0	0
18	.793893	18	.095492	18	324	0	0
19	.654508	19	.024472	19	342	0	0
20	.500000	20	.000000	20	360	0	0

21 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

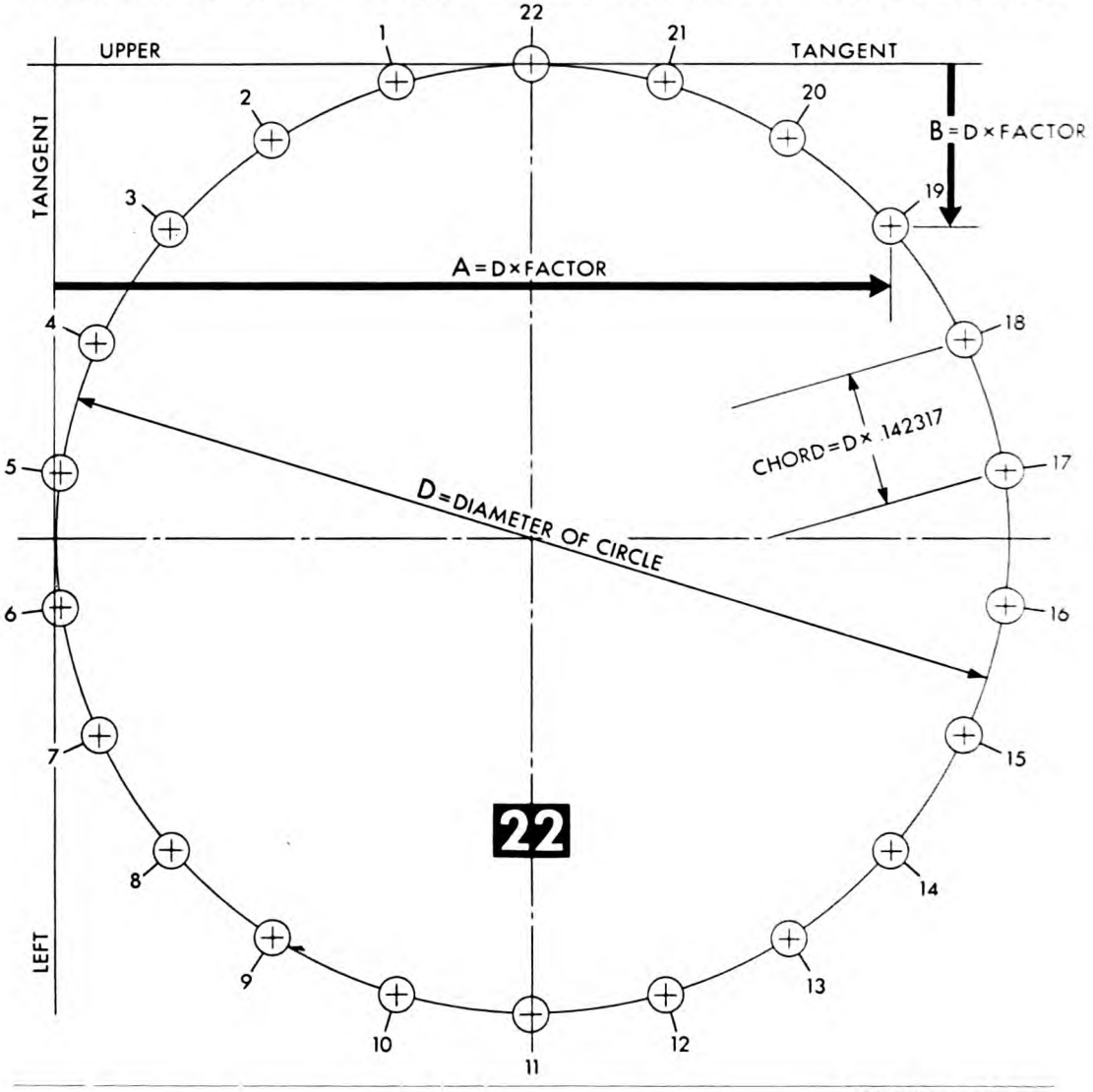


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.352622	1	.022214	1	17	8 34- 6/21
2	.218340	2	.086881	2	34	17 8-12/21
3	.109084	3	.188255	3	51	25 42-18/21
4	.034563	4	.317329	4	68	34 17- 3/21
5	.001398	5	.462635	5	85	42 51- 9/21
6	.012536	6	.611260	6	102	51 25-15/21
7	.066987	7	.750000	7	120	00 00000000
8	.159914	8	.866526	8	137	8 34- 6/21
9	.283058	9	.950484	9	154	17 8-12/21
10	.425479	10	.994415	10	171	25 42-18/21

COORDINATE FACTORS AND ANGLES—21 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.574521	11	.994415	11	188	34 17- 3/21
12	.716942	12	.950484	12	205	42 51- 9/21
13	.840086	13	.866526	13	222	51 25-15/21
14	.933013	14	.750000	14	240	00 00000000
15	.987464	15	.611260	15	257	8 34- 6/21
16	.998602	16	.462635	16	274	17 8-12/21
17	.965437	17	.317329	17	291	25 42-18/21
18	.890916	18	.188255	18	308	34 17- 3/21
19	.781660	19	.086881	19	325	42 51- 9/21
20	.647378	20	.022214	20	342	51 25-15/21
21	.500000	21	.000000	21	360	0 0

22 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

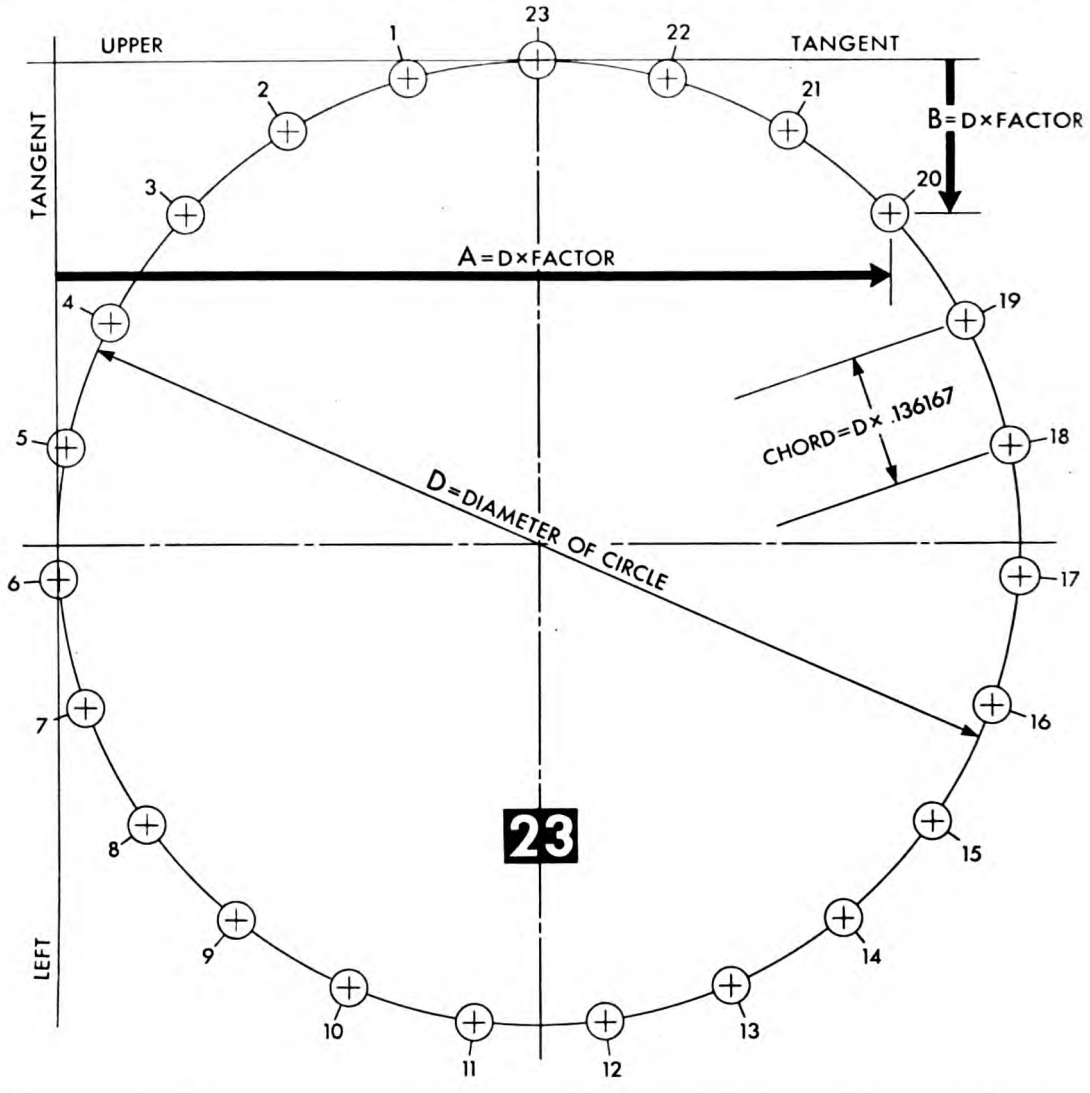


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.359134	1	.020254	1	16	21	49– 2/22
2	.229680	2	.079373	2	32	43	38– 4/22
3	.122125	3	.172570	3	49	5	27– 6/22
4	.045184	4	.292293	4	65	27	16– 8/22
5	.005089	5	.428843	5	81	49	5–10/22
6	.005089	6	.571157	6	98	10	54–12/22
7	.045184	7	.707708	7	114	32	43–14/22
8	.122125	8	.827430	8	130	54	32–16/22
9	.229680	9	.920627	9	147	16	21–18/22
10	.359134	10	.979746	10	163	38	10–20/22

COORDINATE FACTORS AND ANGLES—22 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.500000	11	1.000000	11	180	00	00000000
12	.640866	12	.979746	12	196	21	49– 2/22
13	.770320	13	.920627	13	212	43	38– 4/22
14	.877875	14	.827430	14	229	5	27– 6/22
15	.954816	15	.707708	15	245	27	16– 8/22
16	.994911	16	.571157	16	261	49	5–10/22
17	.994911	17	.428843	17	278	10	54–12/22
18	.954816	18	.292293	18	294	32	43–14/22
19	.877875	19	.172570	19	310	54	32–16/22
20	.770320	20	.079373	20	327	16	21–18/22
21	.640866	21	.020254	21	343	38	10–20/22
22	.500000	22	.000000	22	360	0	0

23 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

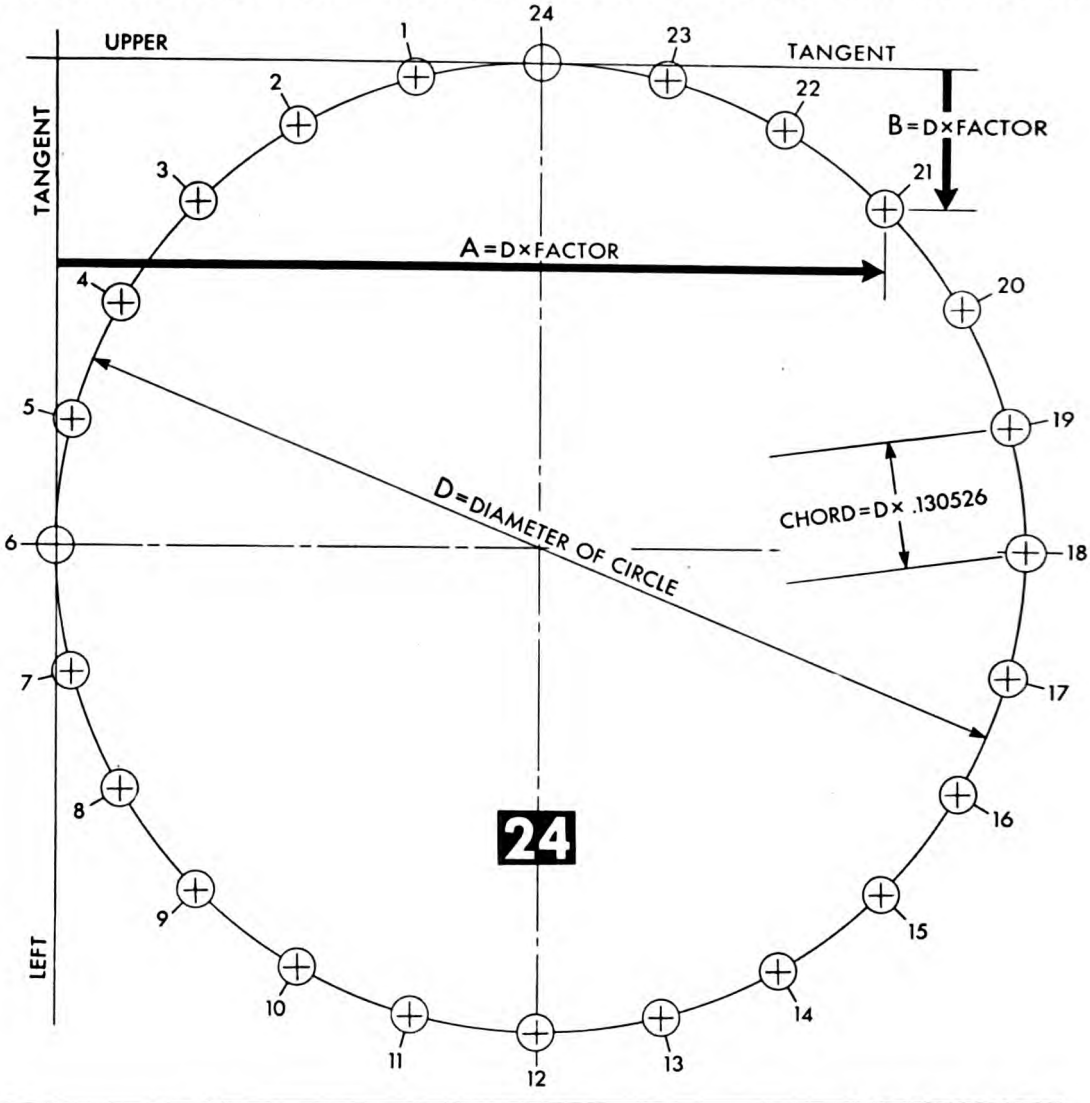


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.365102	1	.018541	1	15	39 7–19/23
2	.240208	2	.072790	2	31	18 15–15/23
3	.134582	3	.158723	3	46	57 23–11/23
4	.056057	4	.269967	4	62	36 31– 7/23
5	.010458	5	.398272	5	78	15 39– 3/23
6	.001166	6	.534121	6	93	54 46–22/23
7	.028870	7	.667440	7	109	33 54–18/23
8	.091515	8	.788340	8	125	13 2–14/23
9	.184456	9	.887856	9	140	52 10–10/23
10	.300803	10	.958606	10	156	31 18– 6/23

COORDINATE FACTORS AND ANGLES—23 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.431917	11	.995343	11	172	10	26- 2/23
12	.568083	12	.995343	12	187	49	33-21/23
13	.699197	13	.958606	13	203	28	41-17/23
14	.815544	14	.887856	14	219	7	49-13/23
15	.908485	15	.788340	15	234	46	57- 9/23
16	.971130	16	.667440	16	250	26	5- 5/23
17	.998834	17	.534121	17	266	5	13- 1/23
18	.989542	18	.398272	18	281	44	20-20/23
19	.943943	19	.269967	19	297	23	28-16/23
20	.865418	20	.158723	20	313	2	36-12/23
21	.759792	21	.072790	21	328	41	44- 8/23
22	.634898	22	.018541	22	344	20	52- 4/23
23	.500000	23	.000000	23	360	0	0

24 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

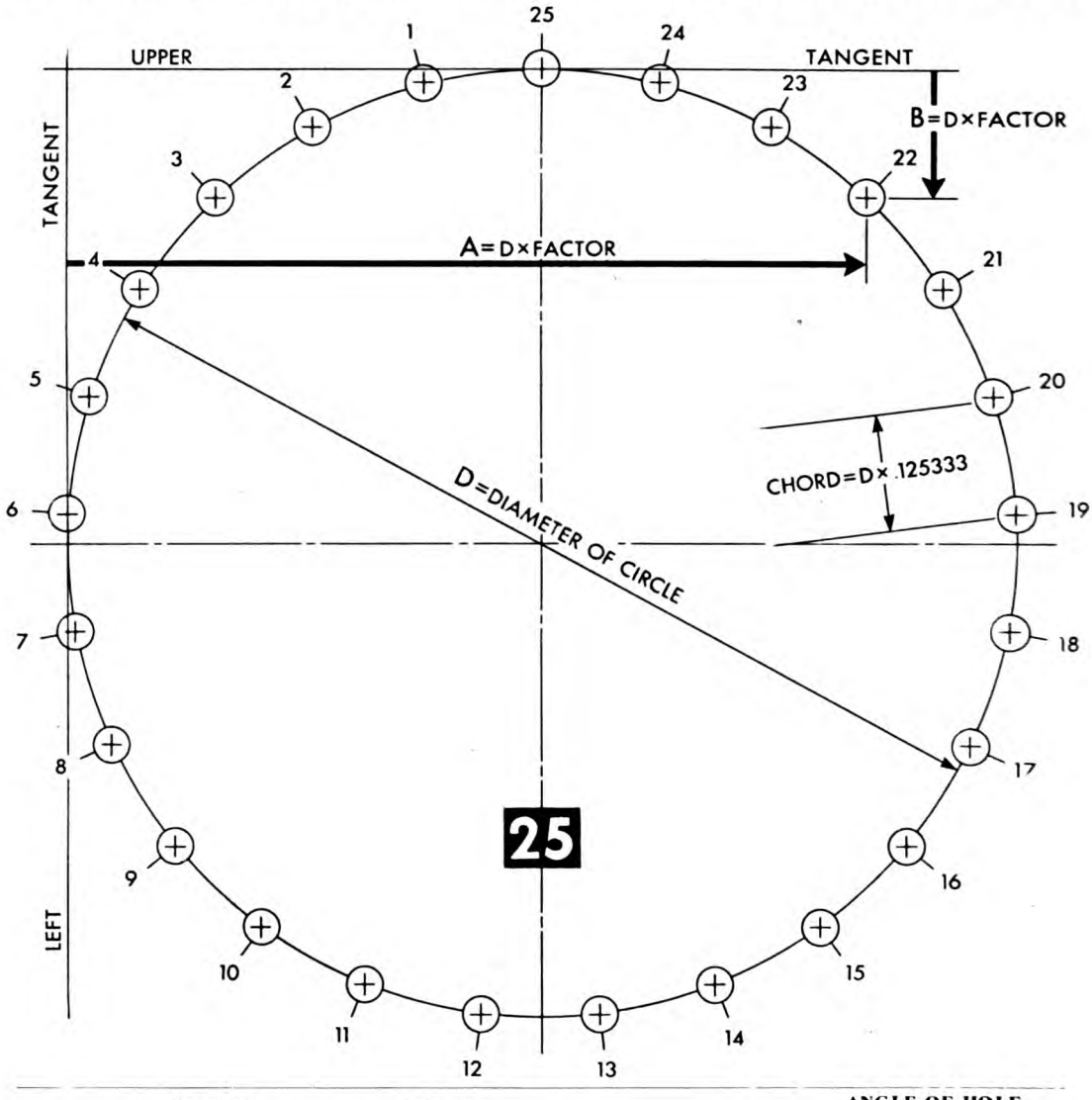


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.370590	1	.017037	1	15	0	0
2	.250000	2	.066987	2	30	0	0
3	.146447	3	.146447	3	45	0	0
4	.066987	4	.250000	4	60	0	0
5	.017037	5	.370590	5	75	0	0
6	.000000	6	.500000	6	90	0	0
7	.017037	7	.629410	7	105	0	0
8	.066987	8	.750000	8	120	0	0
9	.146447	9	.853553	9	135	0	0
10	.250000	10	.933013	10	150	0	0

COORDINATE FACTORS AND ANGLES—24 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.370590	11	.982963	11	165	0	0
12	.500000	12	1.000000	12	180	0	0
13	.629410	13	.982963	13	195	0	0
14	.750000	14	.933013	14	210	0	0
15	.853553	15	.853553	15	225	0	0
16	.933013	16	.750000	16	240	0	0
17	.982963	17	.629410	17	255	0	0
18	1.000000	18	.500000	18	270	0	0
19	.982963	19	.370590	19	285	0	0
20	.933013	20	.250000	20	300	0	0
21	.853553	21	.146447	21	315	0	0
22	.750000	22	.066987	22	330	0	0
23	.629410	23	.017037	23	345	0	0
24	.500000	24	.000000	24	360	0	0

25 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

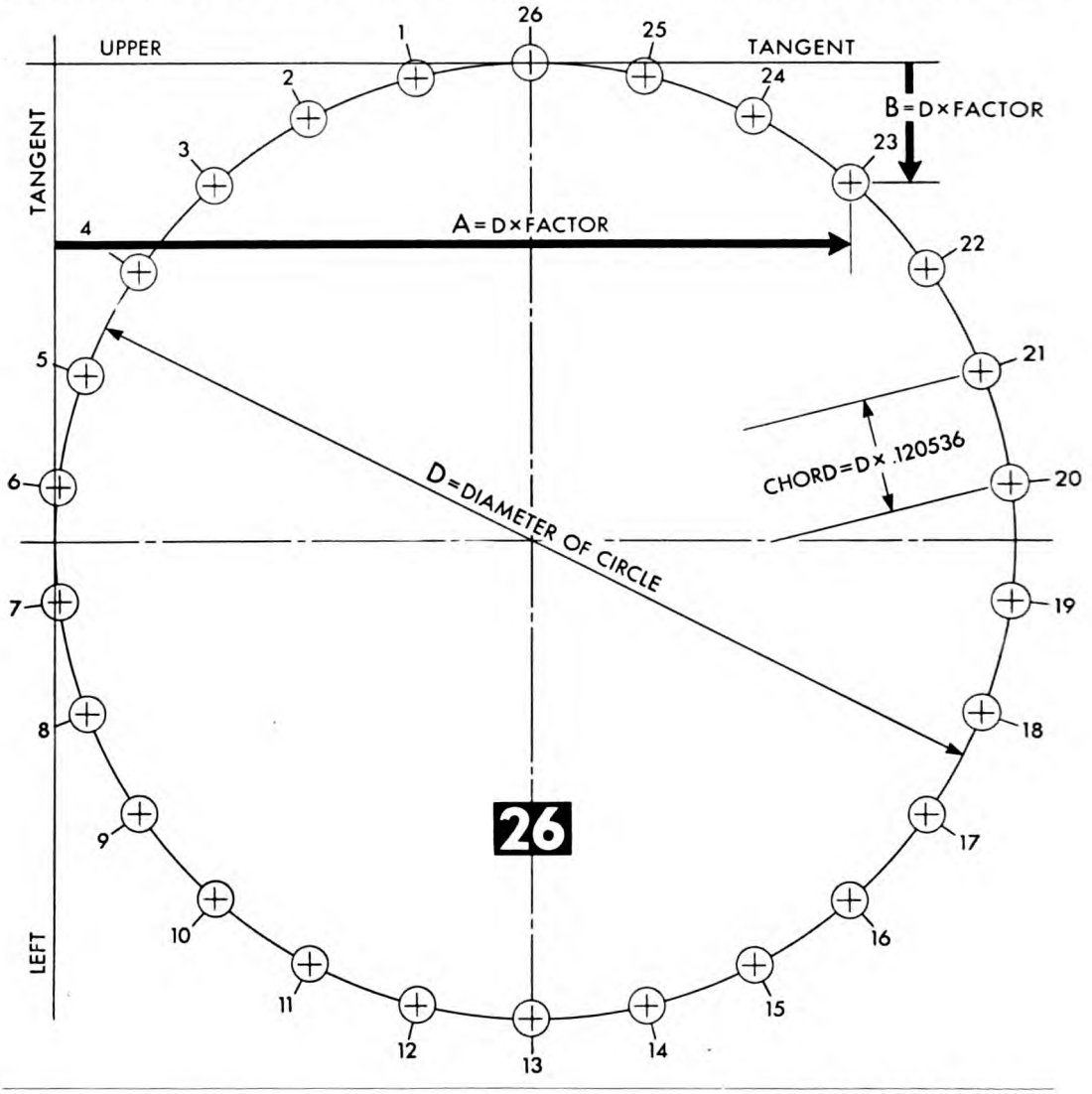


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.375655	1	.015708	1	14	24	0
2	.259123	2	.061847	2	28	48	0
3	.157726	3	.135516	3	43	12	0
4	.077836	4	.232087	4	57	36	0
5	.024472	5	.345492	5	72	00	0
6	.000987	6	.468605	6	86	24	0
7	.008856	7	.593691	7	100	48	0
8	.047586	8	.712890	8	115	12	0
9	.114743	9	.818712	9	129	36	0
10	.206107	10	.904508	10	144	00	0

COORDINATE FACTORS AND ANGLES—25 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.315937	11	.964888	11	158	24	0
12	.437333	12	.996057	12	172	48	0
13	.562667	13	.996057	13	187	12	0
14	.684062	14	.964888	14	201	36	0
15	.793893	15	.904508	15	216	00	0
16	.885257	16	.818712	16	230	24	0
17	.952414	17	.712890	17	244	48	0
18	.991144	18	.593691	18	259	12	0
19	.999013	19	.468605	19	273	36	0
20	.975528	20	.345492	20	288	00	0
21	.922164	21	.232087	21	302	24	0
22	.842274	22	.135516	22	316	48	0
23	.740877	23	.061847	23	331	12	0
24	.624345	24	.015708	24	345	36	0
25	.500000	25	.000000	25	360	0	0

26 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

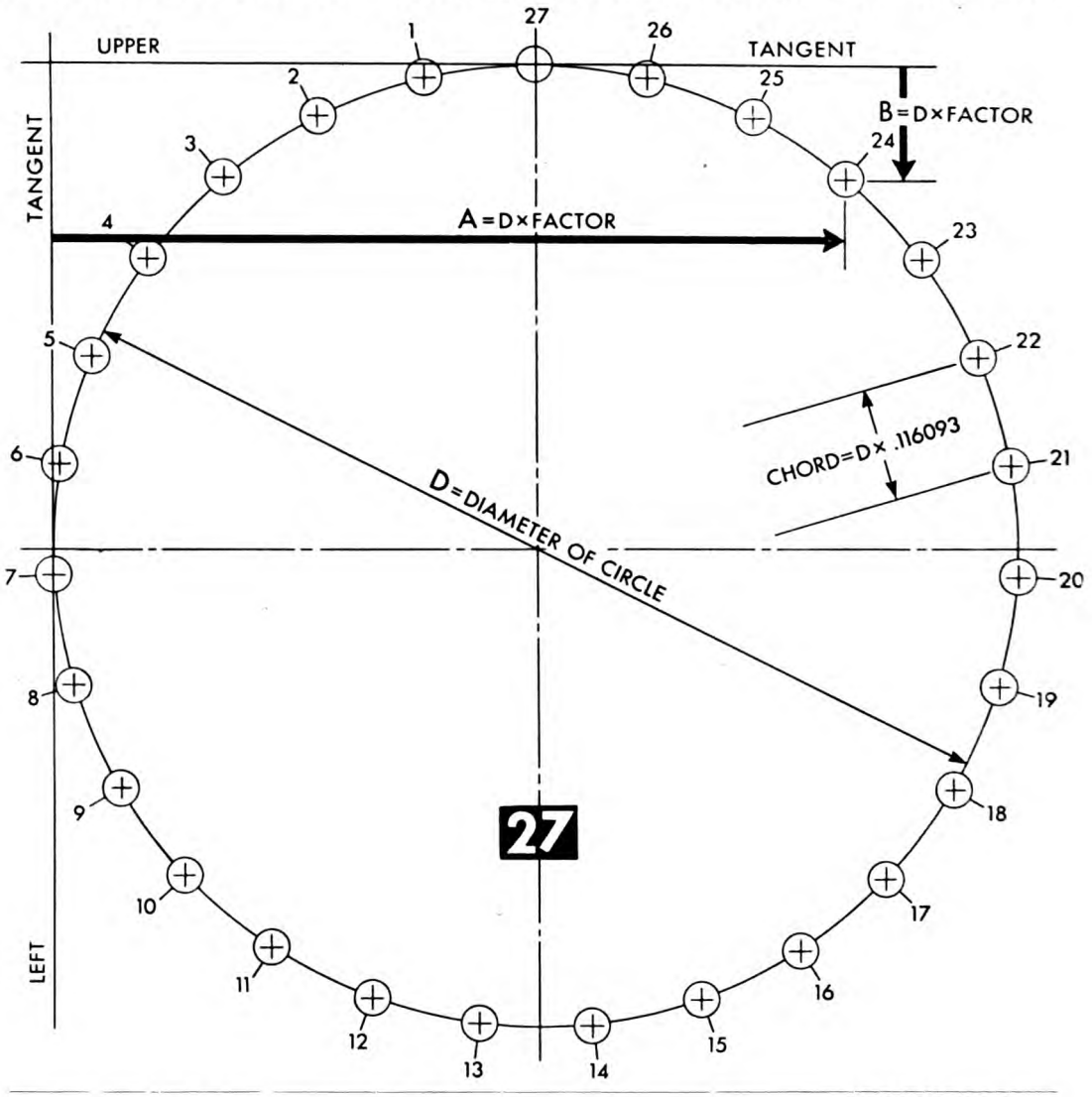


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.380342	1	.014529	1	13	50 45– 4/26
2	.267638	2	.057272	2	27	41 32– 8/26
3	.168439	3	.125745	3	41	32 18–12/26
4	.088508	4	.215968	4	55	23 4–16/26
5	.032492	5	.322698	5	69	13 50–20/26
6	.003646	6	.439732	6	83	4 36–24/26
7	.003646	7	.560268	7	96	55 23– 2/26
8	.032492	8	.677302	8	110	46 9– 6/26
9	.088508	9	.784032	9	124	36 55–10/26
10	.168439	10	.874255	10	138	27 41–14/26

COORDINATE FACTORS AND ANGLES—26 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.267638	11	.942728	11	152	18	27–18/26
12	.380342	12	.985471	12	166	9	13–22/26
13	.500000	13	1.000000	13	180	00	00000000
14	.619658	14	.985471	14	193	50	46– 4/26
15	.732362	15	.942728	15	207	41	32– 8/26
16	.831561	16	.874255	16	221	32	18–12/26
17	.911492	17	.784032	17	235	23	4–16/26
18	.967508	18	.677302	18	249	13	50–20/26
19	.996354	19	.560268	19	263	4	36–24/26
20	.996354	20	.439732	20	276	55	23– 2/26
21	.967508	21	.322698	21	290	46	9– 6/26
22	.911492	22	.215968	22	304	36	55–10/26
23	.831561	23	.125745	23	318	27	41–14/26
24	.732362	24	.057272	24	332	18	27–18/26
25	.619658	25	.014529	25	346	9	13–22/26
26	.500000	26	.000000	26	360	0	0

27 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

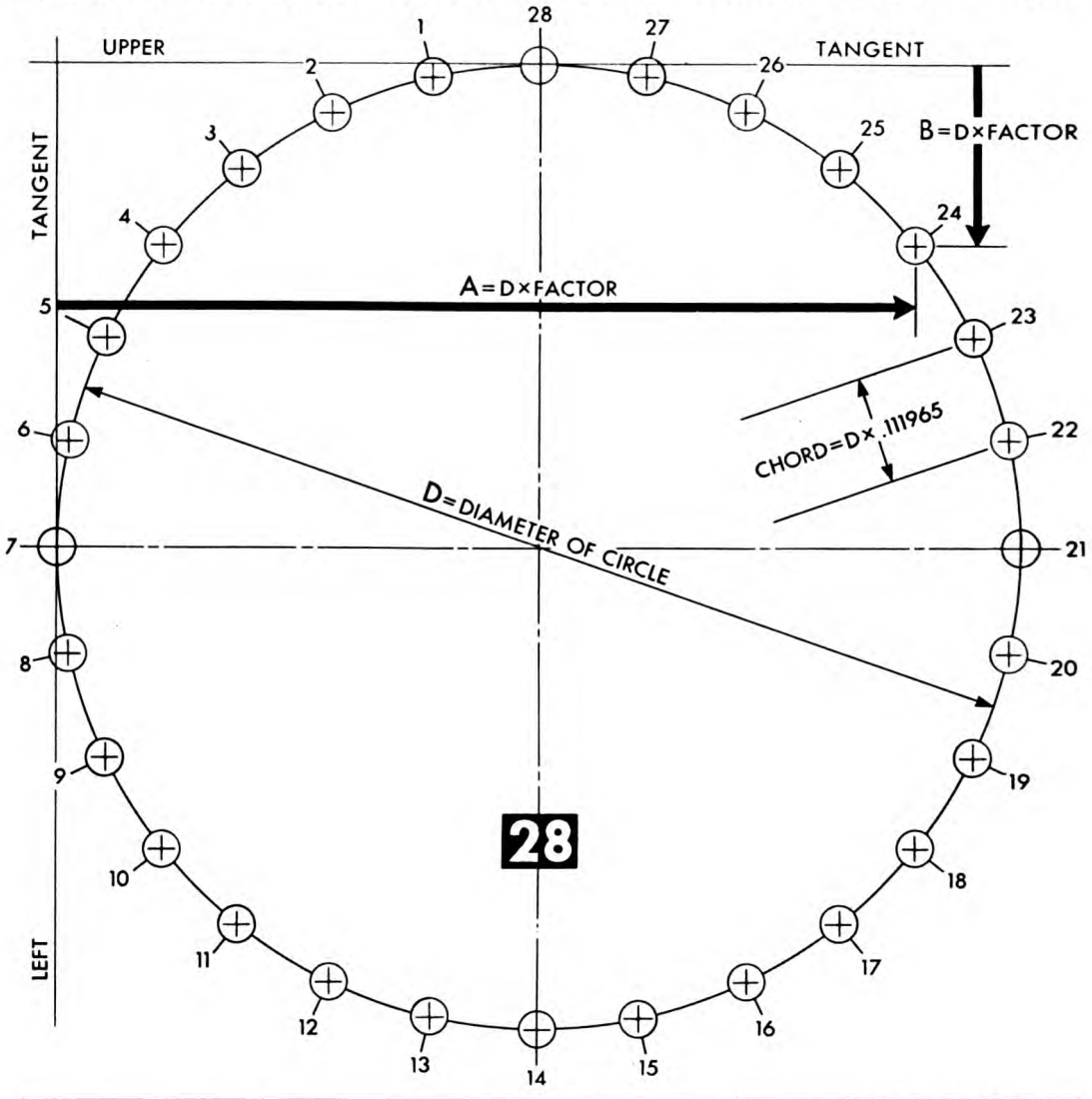


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.384692	1	.013478	1	13	20	0
2	.275600	2	.053184	2	26	40	0
3	.178606	3	.116978	3	40	00	0
4	.098938	4	.201421	4	53	20	0
5	.040892	5	.301960	5	66	40	0
6	.007596	6	.413176	6	80	00	0
7	.000846	7	.529072	7	93	20	0
8	.021005	8	.643402	8	106	40	0
9	.066987	9	.750000	9	120	00	0
10	.136313	10	.843121	10	133	20	0

COORDINATE FACTORS AND ANGLES—27 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.225246	11	.917744	11	146	40	0
12	.328990	12	.969846	12	160	00	0
13	.441954	13	.996619	13	173	20	0
14	.558046	14	.996619	14	186	40	0
15	.671010	15	.969846	15	200	00	0
16	.774755	16	.917744	16	213	20	0
17	.863687	17	.843121	17	226	40	0
18	.933013	18	.750000	18	240	00	0
19	.978995	19	.643402	19	253	20	0
20	.999154	20	.529072	20	266	40	0
21	.992404	21	.413176	21	280	00	0
22	.959108	22	.301960	22	293	20	0
23	.901062	23	.201421	23	306	40	0
24	.821394	24	.116978	24	320	00	0
25	.724400	25	.053184	25	333	20	0
26	.615308	26	.013478	26	346	40	0
27	.500000	27	.000000	27	360	0	0

28 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

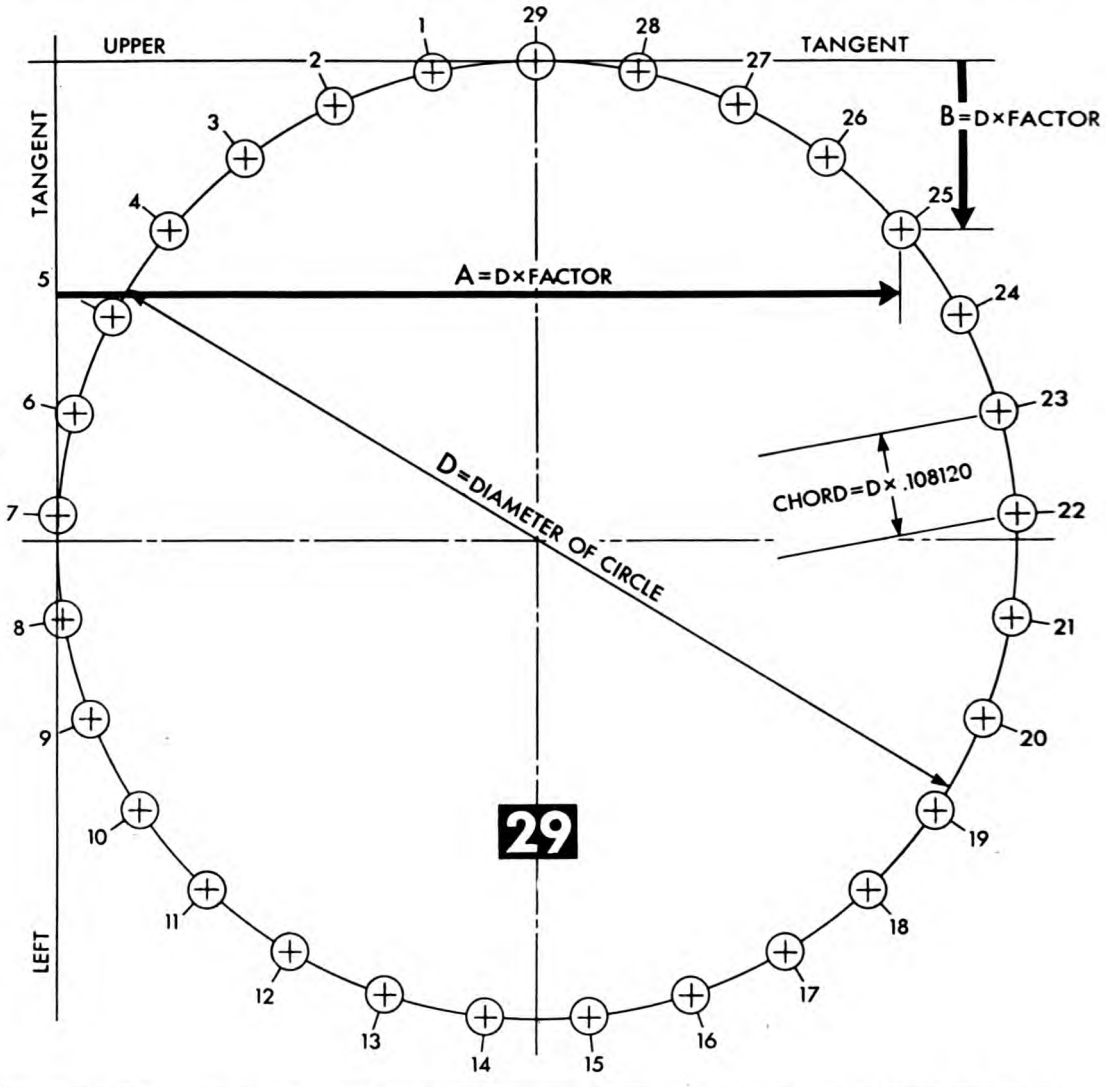


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.388740	1	.012536	1	12	51 25–20/28
2	.283058	2	.049516	2	25	42 51–12/28
3	.188255	3	.109084	3	38	34 17– 4/28
4	.109084	4	.188255	4	51	25 42–24/28
5	.049516	5	.283058	5	64	17 8–16/28
6	.012536	6	.388740	6	77	8 34– 8/28
7	.000000	7	.500000	7	90	00 00000000
8	.012536	8	.611261	8	102	51 25–20/28
9	.049516	9	.716942	9	115	42 51–12/28
10	.109084	10	.811745	10	128	34 17– 4/28

COORDINATE FACTORS AND ANGLES—28 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.188255	11	.890916	11	141	25	42-24/28
12	.283058	12	.950484	12	154	17	8-16/28
13	.388740	13	.987464	13	167	8	34- 8/28
14	.500000	14	1.000000	14	180	00	00000000
15	.611261	15	.987464	15	192	51	25-20/28
16	.716942	16	.950484	16	205	42	51-12/28
17	.811745	17	.890916	17	218	34	17- 4/28
18	.890916	18	.811745	18	231	25	42-24/28
19	.950484	19	.716942	19	244	17	8-16/28
20	.987464	20	.611261	20	257	8	34- 8/28
21	1.000000	21	.500000	21	270	00	00000000
22	.987464	22	.388740	22	282	51	25-20/28
23	.950484	23	.283058	23	295	42	51-12/28
24	.890916	24	.188255	24	308	34	17- 4/28
25	.811745	25	.109084	25	321	25	42-24/28
26	.716942	26	.049516	26	334	17	8-16/28
27	.611261	27	.012536	27	347	8	34- 8/28
28	.500000	28	.000000	28	360	0	0

29 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

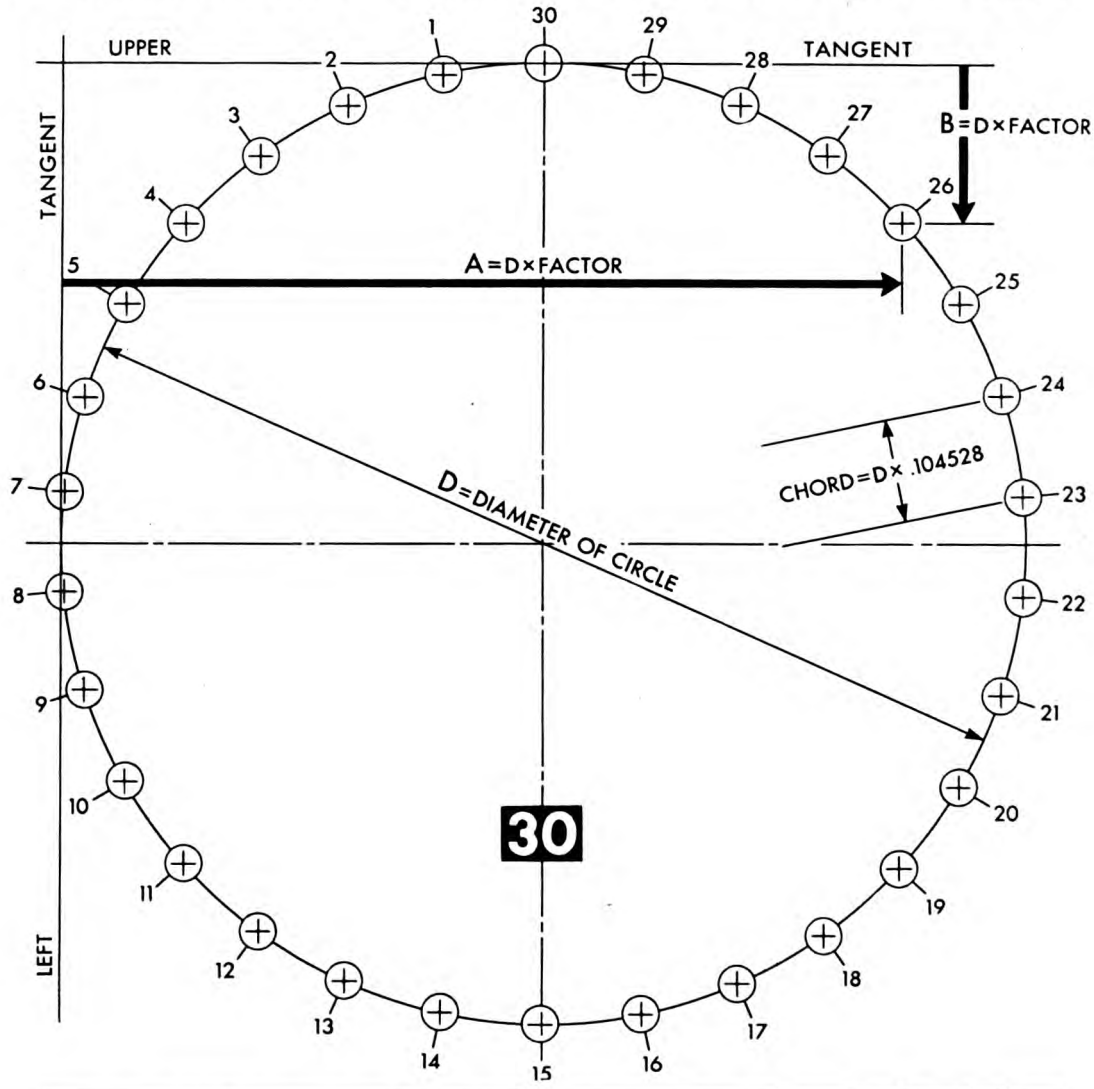


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.392515	1	.011689	1	12	24 49-19/29
2	.290056	2	.046212	2	24	49 39- 9/29
3	.197413	3	.101954	3	37	14 28-28/29
4	.118919	4	.176305	4	49	39 18-18/29
5	.058244	5	.265796	5	62	4 8- 8/29
6	.018225	6	.366236	6	74	28 57-27/29
7	.000733	7	.472931	7	86	53 47-17/29
8	.006587	8	.580891	8	99	18 37- 7/29
9	.035512	9	.685069	9	111	43 26-26/29
10	.086155	10	.780594	10	124	8 16-16/29

COORDINATE FACTORS AND ANGLES—29 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.156150	11	.862998	11	136	33	6- 6/29
12	.242223	12	.928429	12	148	57	55-25/29
13	.340349	13	.973827	13	161	22	45-15/29
14	.445941	14	.997069	14	173	47	35- 5/29
15	.554060	15	.997069	15	186	12	24-24/29
16	.659651	16	.973827	16	198	37	14-14/29
17	.757777	17	.928429	17	211	2	4- 4/29
18	.843850	18	.862998	18	223	26	53-23/29
19	.913844	19	.780594	19	235	51	43-13/29
20	.964488	20	.685069	20	248	16	33- 3/29
21	.993413	21	.580891	21	260	41	22-22/29
22	.999267	22	.472931	22	273	6	12-12/29
23	.981775	23	.366236	23	285	31	2- 2/29
24	.941756	24	.265796	24	297	55	51-21/29
25	.881081	25	.176305	25	310	20	41-11/29
26	.802587	26	.101954	26	322	45	31- 1/29
27	.709945	27	.046212	27	335	10	20-20/29
28	.607485	28	.011689	28	347	35	10-10/29
29	.500000	29	.000000	29	360	0	0

30 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

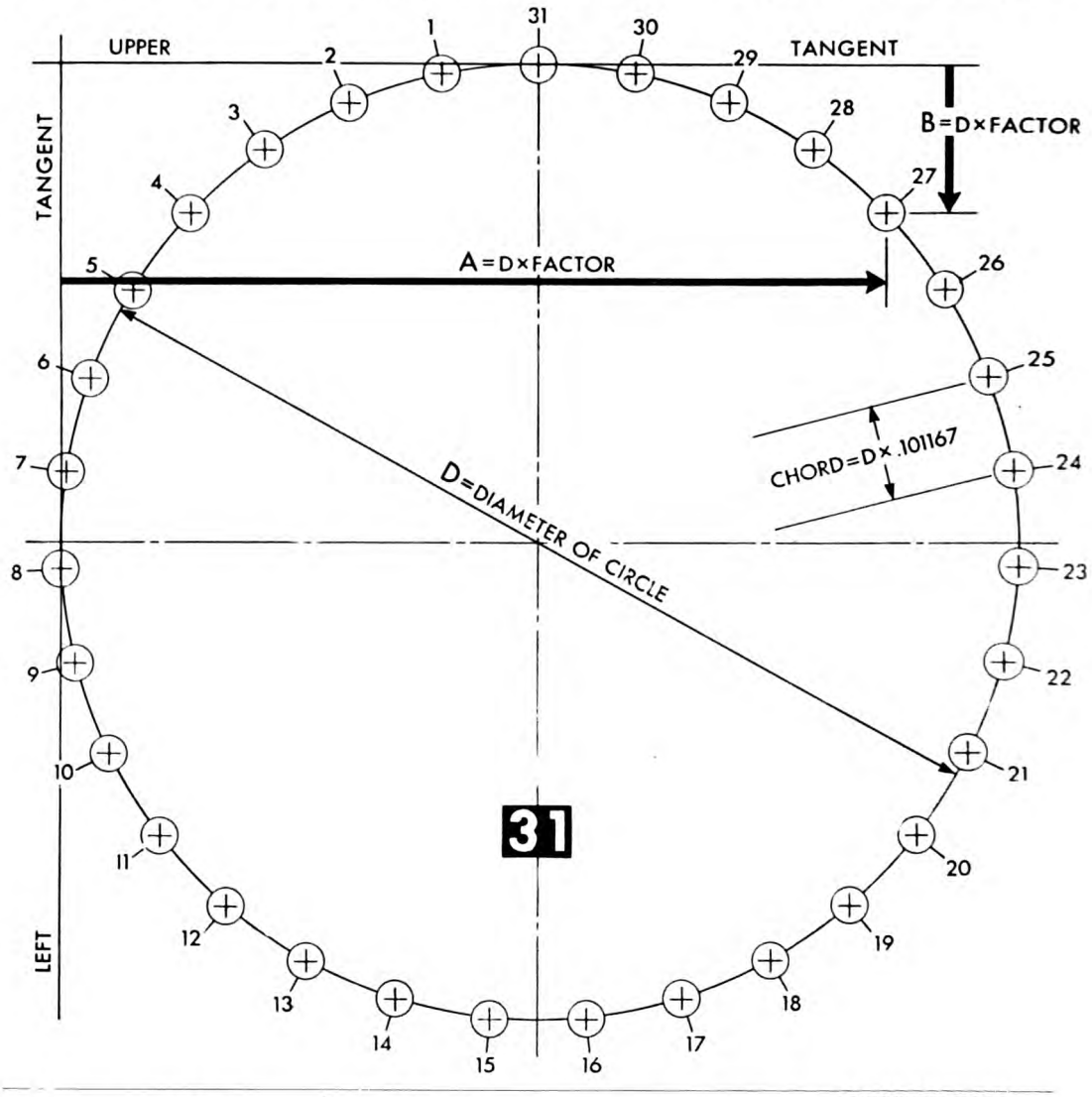


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.396044	1	.010926	1	12	0	0
2	.296632	2	.043227	2	24	0	0
3	.206107	3	.095492	3	36	0	0
4	.128428	4	.165435	4	48	0	0
5	.066987	5	.250000	5	60	0	0
6	.024472	6	.345492	6	72	0	0
7	.002739	7	.447736	7	84	0	0
8	.002739	8	.552264	8	96	0	0
9	.024472	9	.654509	9	108	0	0
10	.066987	10	.750000	10	120	0	0

COORDINATE FACTORS AND ANGLES—30 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.128428	11	.834565	11	132	0	0
12	.206107	12	.904509	12	144	0	0
13	.296632	13	.956773	13	156	0	0
14	.396044	14	.989074	14	168	0	0
15	.500000	15	1.000000	15	180	0	0
16	.603956	16	.989074	16	192	0	0
17	.703368	17	.956773	17	204	0	0
18	.793893	18	.904509	18	216	0	0
19	.871572	19	.834565	19	228	0	0
20	.933013	20	.750000	20	240	0	0
21	.975528	21	.654509	21	252	0	0
22	.997261	22	.552264	22	264	0	0
23	.997261	23	.447736	23	276	0	0
24	.975528	24	.345492	24	288	0	0
25	.933013	25	.250000	25	300	0	0
26	.871572	26	.165435	26	312	0	0
27	.793893	27	.095492	27	324	0	0
28	.703368	28	.043227	28	336	0	0
29	.603956	29	.010926	29	348	0	0
30	.500000	30	.000000	30	360	0	0

31 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

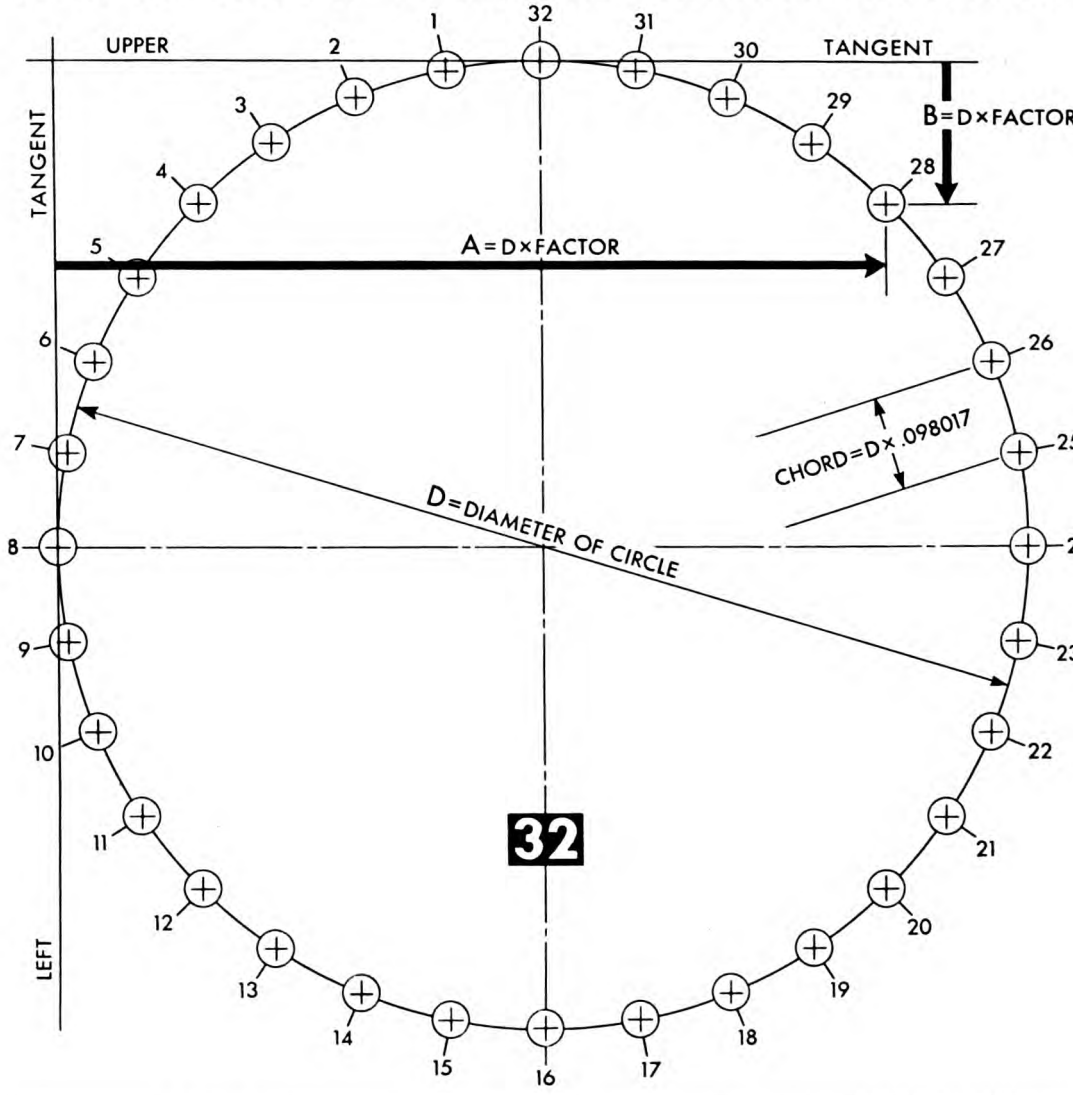


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.399351	1	.010235	1	11	36	46-14/31
2	.302822	2	.040521	2	23	13	32-28/31
3	.214366	3	.089618	3	34	50	19-11/31
4	.137604	4	.155517	4	46	27	5-25/31
5	.075678	5	.235518	5	58	3	52- 8/31
6	.031124	6	.326347	6	69	40	38-22/31
7	.005766	7	.424286	7	81	17	25- 5/31
8	.000642	8	.525325	8	92	54	11-19/31
9	.015961	9	.625326	9	104	30	58- 2/31
10	.051098	10	.720197	10	116	7	44-16/31

COORDINATE FACTORS AND ANGLES—31 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.104612	11	.806053	11	127	44	30–30/31
12	.174314	12	.879379	12	139	21	17–13/31
13	.257349	13	.937173	13	150	58	3–27/31
14	.350318	14	.977070	14	162	34	50–10/31
15	.449416	15	.997435	15	174	11	36–24/31
16	.550584	16	.997435	16	185	48	23– 7/31
17	.649682	17	.977070	17	197	25	9–21/31
18	.742651	18	.937173	18	209	1	56– 4/31
19	.825686	19	.879379	19	220	38	42–18/31
20	.895388	20	.806053	20	232	15	29– 1/31
21	.948902	21	.720197	21	243	52	15–15/31
22	.984039	22	.625326	22	255	29	1–29/31
23	.999358	23	.525325	23	267	5	48–12/31
24	.994234	24	.424286	24	278	42	34–26/31
25	.968876	25	.326347	25	290	19	21– 9/31
26	.924322	26	.235518	26	301	56	7–23/31
27	.862396	27	.155517	27	313	32	54– 6/31
28	.785634	28	.089618	28	325	9	40–20/31
29	.697178	29	.040521	29	336	46	27– 3/31
30	.600649	30	.010235	30	348	23	13–17/31
31	.500000	31	.000000	31	360	0	0

32 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

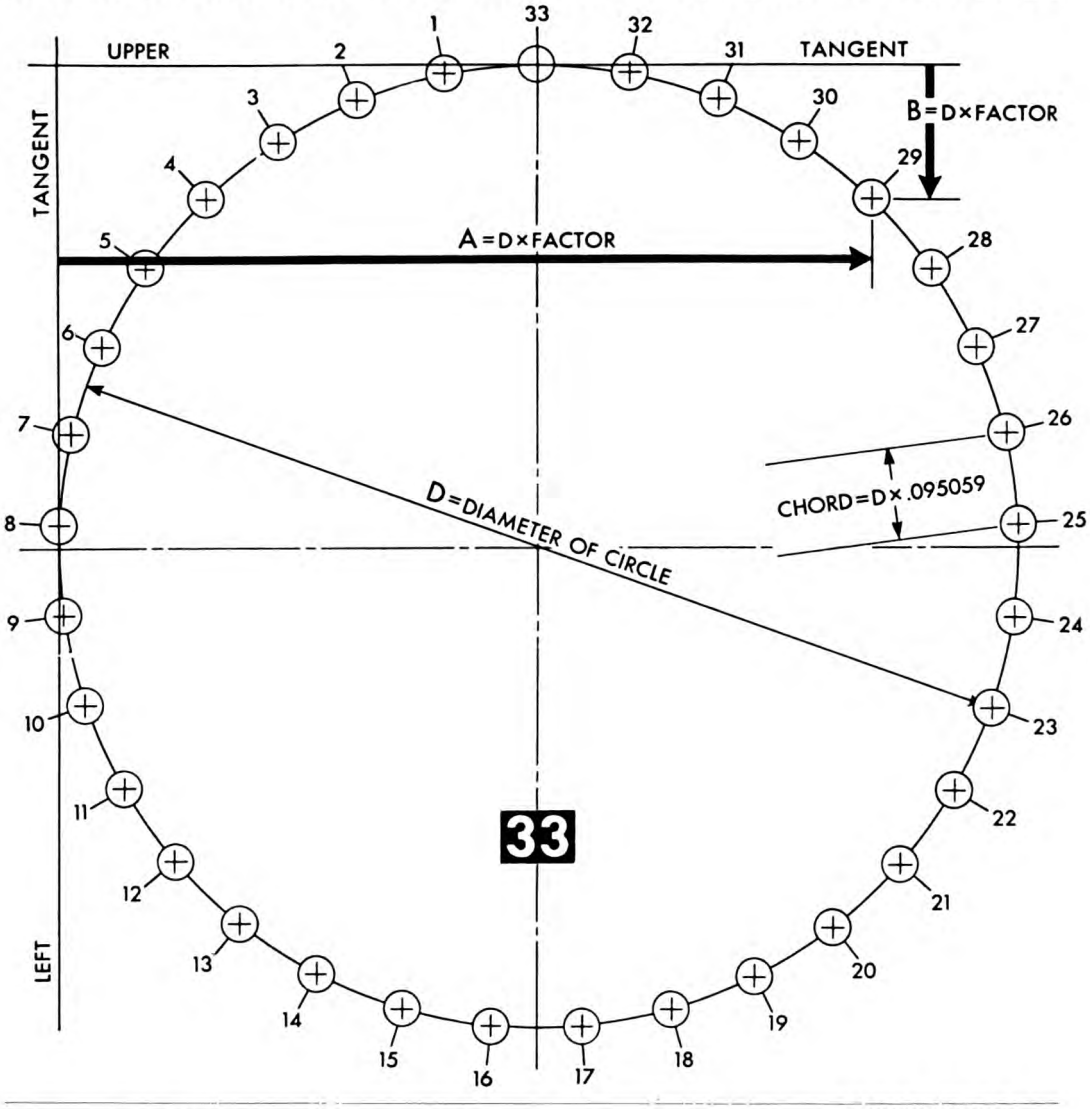


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.402455	1	.009607	1	11	15	0
2	.308658	2	.038060	2	22	30	0
3	.222215	3	.084265	3	33	45	0
4	.146447	4	.146447	4	45	00	0
5	.084265	5	.222215	5	56	15	0
6	.038060	6	.308658	6	67	30	0
7	.009607	7	.402455	7	78	45	0
8	.000000	8	.500000	8	90	00	0
9	.009607	9	.597545	9	101	15	0
10	.038060	10	.691342	10	112	30	0

COORDINATE FACTORS AND ANGLES—32 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.084265	11	.777785	11	123	45	0
12	.146447	12	.853553	12	135	00	0
13	.222215	13	.915735	13	146	15	0
14	.308658	14	.961940	14	157	30	0
15	.402455	15	.990393	15	168	45	0
16	.500000	16	1.000000	16	180	00	0
17	.597545	17	.990393	17	191	15	0
18	.691342	18	.961940	18	202	30	0
19	.777785	19	.915735	19	213	45	0
20	.853553	20	.853553	20	225	00	0
21	.915735	21	.777785	21	236	15	0
22	.961940	22	.691342	22	247	30	0
23	.990393	23	.597545	23	258	45	0
24	1.000000	24	.500000	24	270	00	0
25	.990393	25	.402455	25	281	15	0
26	.961940	26	.308658	26	292	30	0
27	.915735	27	.222215	27	303	45	0
28	.853553	28	.146447	28	315	00	0
29	.777785	29	.084265	29	326	15	0
30	.691342	30	.038060	30	337	30	0
31	.597545	31	.009607	31	348	45	0
32	.500000	32	.000000	32	360	0	0

33 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

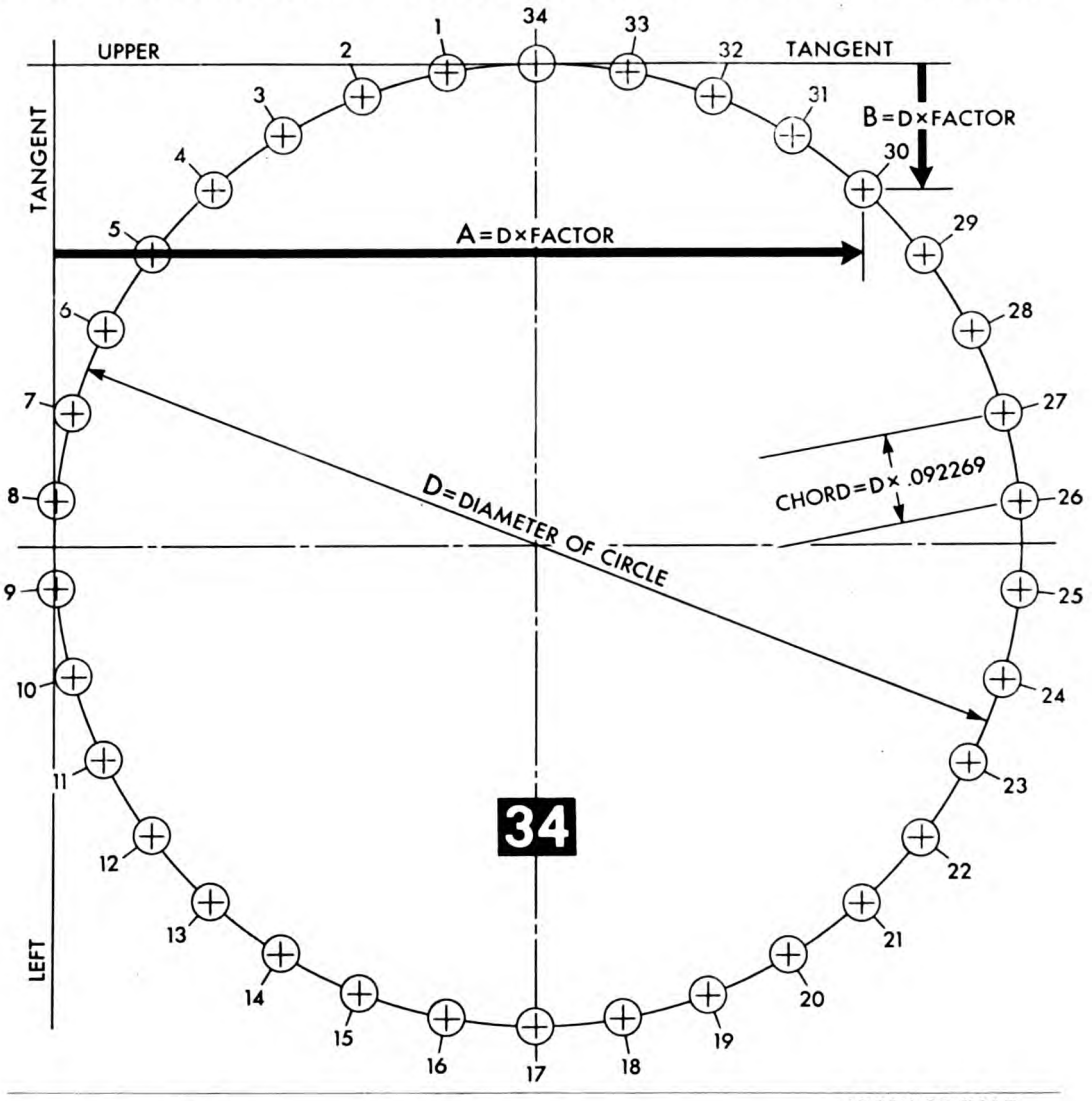


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.405374	1	.009036	1	10	54 32–24/33
2	.314169	2	.035816	2	21	49 5–15/33
3	.229680	3	.079373	3	32	43 38– 6/33
4	.154961	4	.138133	4	43	38 10–30/33
5	.092712	5	.209972	5	54	32 43–21/33
6	.045184	6	.292293	6	65	27 16–12/33
7	.014094	7	.382121	7	76	21 49– 3/33
8	.000566	8	.476209	8	87	16 21–27/33
9	.005089	9	.571157	9	98	10 54–18/33
10	.027500	10	.663534	10	109	5 27– 9/33

COORDINATE FACTORS AND ANGLES—33 HOLE DIVISION

➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.066987	11	.750000	11	120	00	00000000
12	.122125	12	.827430	12	130	54	32–24/33
13	.190921	13	.893027	13	141	49	5–15/33
14	.270887	14	.944418	14	152	43	38– 6/33
15	.359134	15	.979747	15	163	38	10–30/33
16	.452472	16	.997736	16	174	32	43–21/33
17	.547528	17	.997736	17	185	27	16–12/33
18	.640866	18	.979747	18	196	21	49– 3/33
19	.729113	19	.944418	19	207	16	21–27/33
20	.809080	20	.893027	20	218	10	54–18/33
21	.877875	21	.827430	21	229	5	27– 9/33
22	.933013	22	.750000	22	240	00	00000000
23	.972500	23	.663534	23	250	54	32–24/33
24	.994911	24	.571157	24	261	49	5–15/33
25	.999434	25	.476209	25	272	43	38– 6/33
26	.985906	26	.382121	26	283	38	10–30/33
27	.954816	27	.292293	27	294	32	43–21/33
28	.907288	28	.209972	28	305	27	16–12/33
29	.845040	29	.138133	29	316	21	49– 3/33
30	.770320	30	.079373	30	327	16	21–27/33
31	.685831	31	.035816	31	338	10	54–18/33
32	.594626	32	.009036	32	349	5	27– 9/33
33	.500000	33	.000000	33	360	0	0

34 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

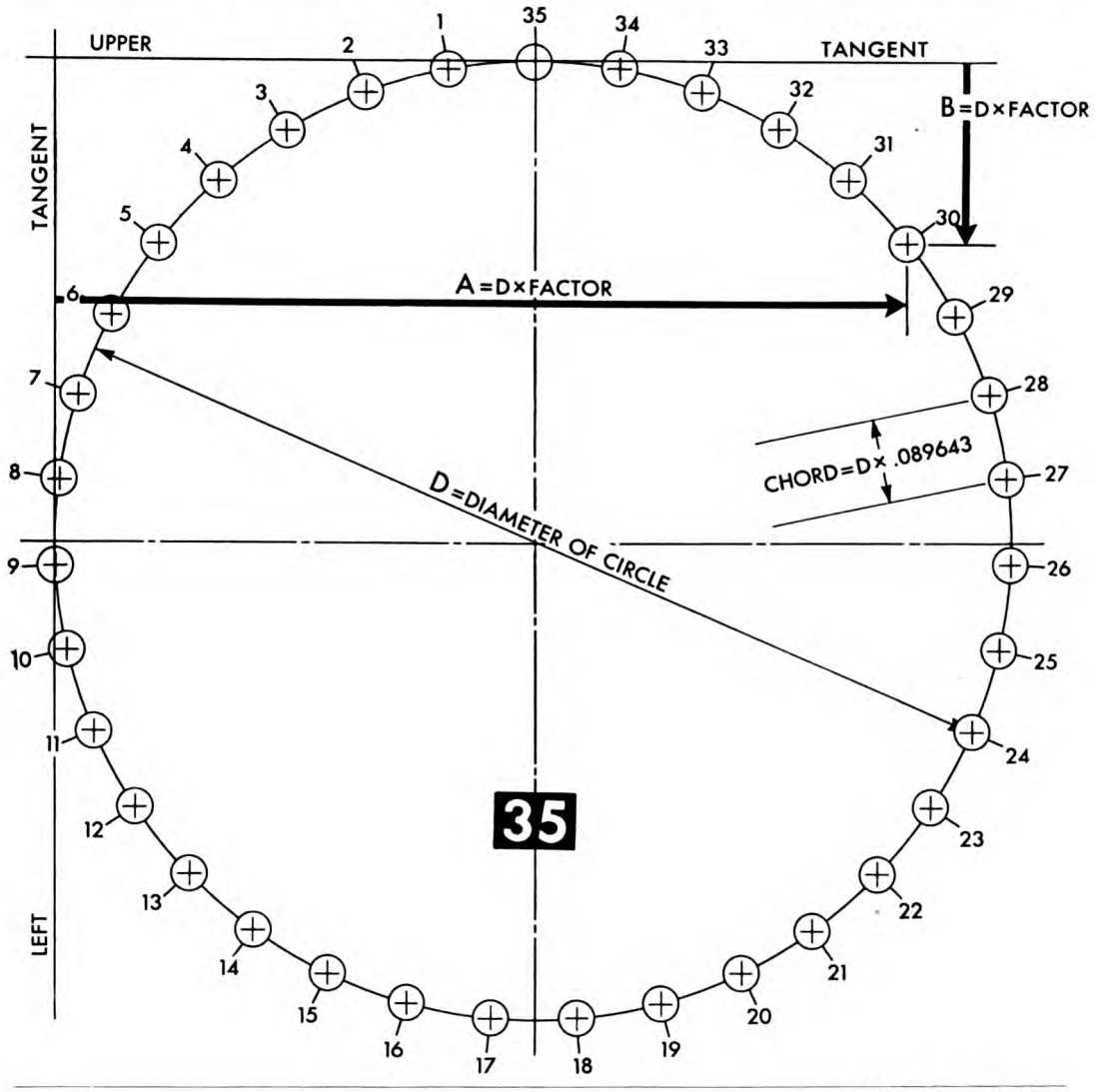


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.408125	1	.008514	1	10	35 17-22/34
2	.319379	2	.033764	2	21	10 35-10/34
3	.236784	3	.074891	3	31	45 52-32/34
4	.163152	4	.130496	4	42	21 10-20/34
5	.100991	5	.198683	5	52	56 28- 8/34
6	.052418	6	.277131	6	63	31 45-30/34
7	.019087	7	.363169	7	74	7 3-18/34
8	.002133	8	.453866	8	84	42 21- 6/34
9	.002133	9	.546134	9	95	17 38-28/24
10	.019087	10	.636832	10	105	52 56-16/34

COORDINATE FACTORS AND ANGLES—34 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.052418	11	.722869	11	116	28	14- 4/34
12	.100991	12	.801317	12	127	3	31-26/34
13	.163152	13	.869504	13	137	38	49-14/34
14	.236784	14	.925109	14	148	14	7- 2/34
15	.319379	15	.966236	15	158	49	24-24/34
16	.408125	16	.991487	16	169	24	42-12/34
17	.500000	17	1.000000	17	180	00	00000000
18	.591875	18	.991487	18	190	35	17-22/34
19	.680621	19	.966236	19	201	10	35-10/34
20	.763216	20	.925109	20	211	45	52-32/34
21	.836848	21	.869504	21	222	21	10-20/34
22	.899009	22	.801317	22	232	56	28- 8/34
23	.947582	23	.722869	23	243	31	45-30/34
24	.980913	24	.636832	24	254	7	3-18/34
25	.997867	25	.546134	25	264	42	21- 6/34
26	.997867	26	.453866	26	275	17	38-28/34
27	.980913	27	.363169	27	285	52	56-16/34
28	.947582	28	.277131	28	296	28	14- 4/34
29	.899009	29	.198683	29	307	3	31-26/34
30	.836848	30	.130496	30	317	38	49-14/34
31	.763216	31	.074891	31	328	14	7- 2/34
32	.680621	32	.033764	32	338	49	24-24/34
33	.591875	33	.008514	33	349	24	42-12/34
34	.500000	34	.000000	34	360	0	0

35 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

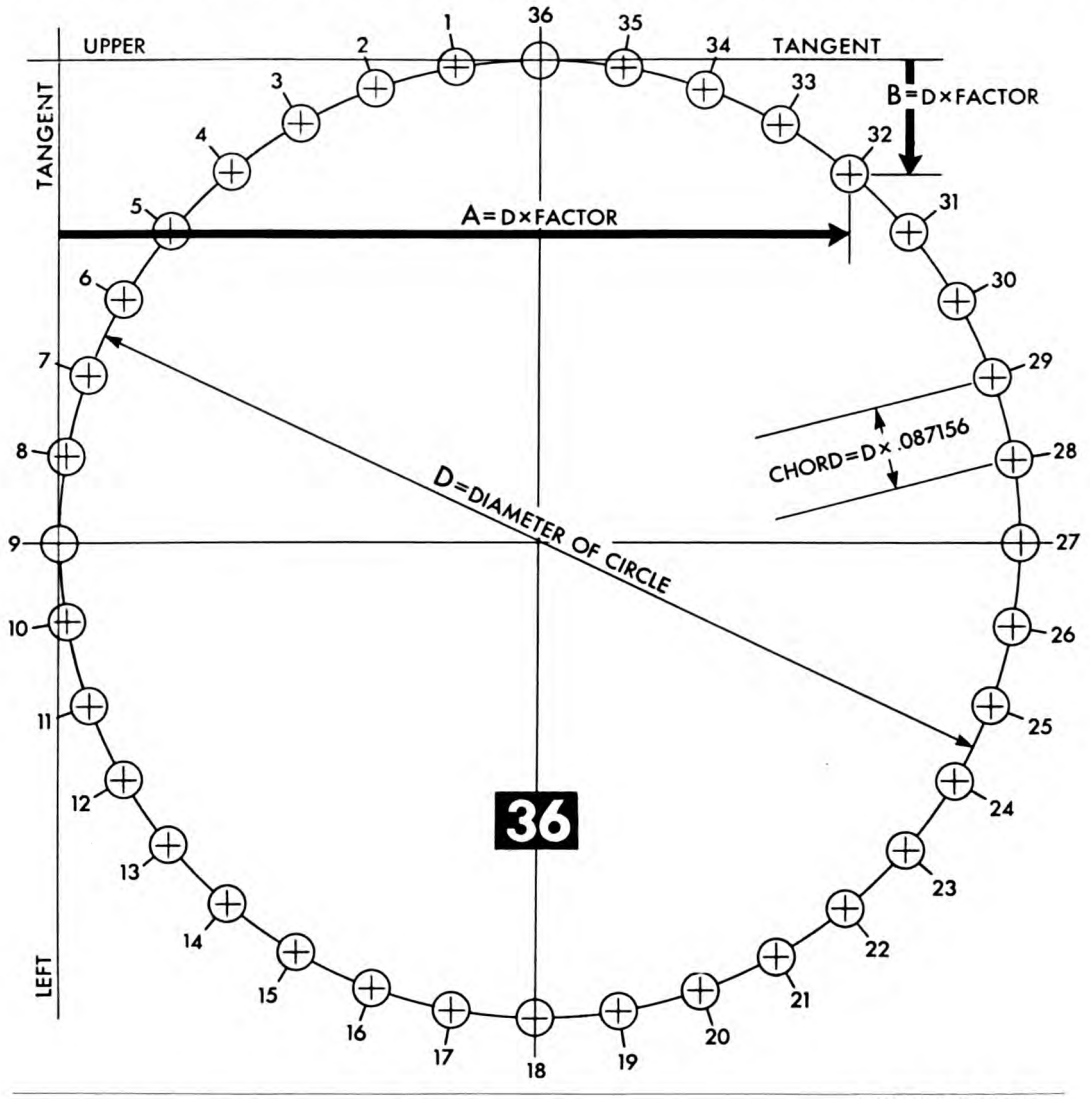


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.410722	1	.008035	1	10	17 8–20/35
2	.324313	2	.031883	2	20	34 17– 5/35
3	.243550	3	.070776	3	30	51 25–25/35
4	.171031	4	.123464	4	41	8 34–10/35
5	.109084	5	.188255	5	51	25 42–30/35
6	.059702	6	.263066	6	61	42 51–15/35
7	.024472	7	.345492	7	72	00 00000000
8	.004525	8	.432883	8	82	17 8–20/35
9	.000504	9	.522433	9	92	34 17– 5/35
10	.012536	10	.611261	10	102	51 25–25/35

COORDINATE FACTORS AND ANGLES—35 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.040236	11	.696513	11	113	8 34–10/35
12	.082713	12	.775449	12	123	25 42–30/35
13	.138603	13	.845531	13	133	42 51–15/35
14	.206107	14	.904509	14	144	00 00000000
15	.283058	15	.950484	15	154	17 8–20/35
16	.366982	16	.981981	16	164	34 17– 5/35
17	.455180	17	.997987	17	174	51 25–25/35
18	.544820	18	.997987	18	185	8 34–10/35
19	.633018	19	.981981	19	195	25 42–30/35
20	.716942	20	.950484	20	205	42 51–15/35
21	.793893	21	.904509	21	216	00 00000000
22	.861397	22	.845531	22	226	17 8–20/35
23	.917287	23	.775449	23	236	34 17– 5/35
24	.959764	24	.696513	24	246	51 25–25/35
25	.987464	25	.611261	25	257	8 34–10/35
26	.999497	26	.522433	26	267	25 42–30/35
27	.995475	27	.432883	27	277	42 51–15/35
28	.975528	28	.345492	28	288	00 00000000
29	.940298	29	.263066	29	298	17 8–20/35
30	.890916	30	.188255	30	308	34 17– 5/35
31	.828969	31	.123464	31	318	51 25–25/35
32	.756450	32	.070776	32	329	8 34–10/35
33	.675687	33	.031883	33	339	25 42–30/35
34	.589278	34	.008035	34	349	42 51–15/35
35	.500000	35	.000000	35	360	0 0

36 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

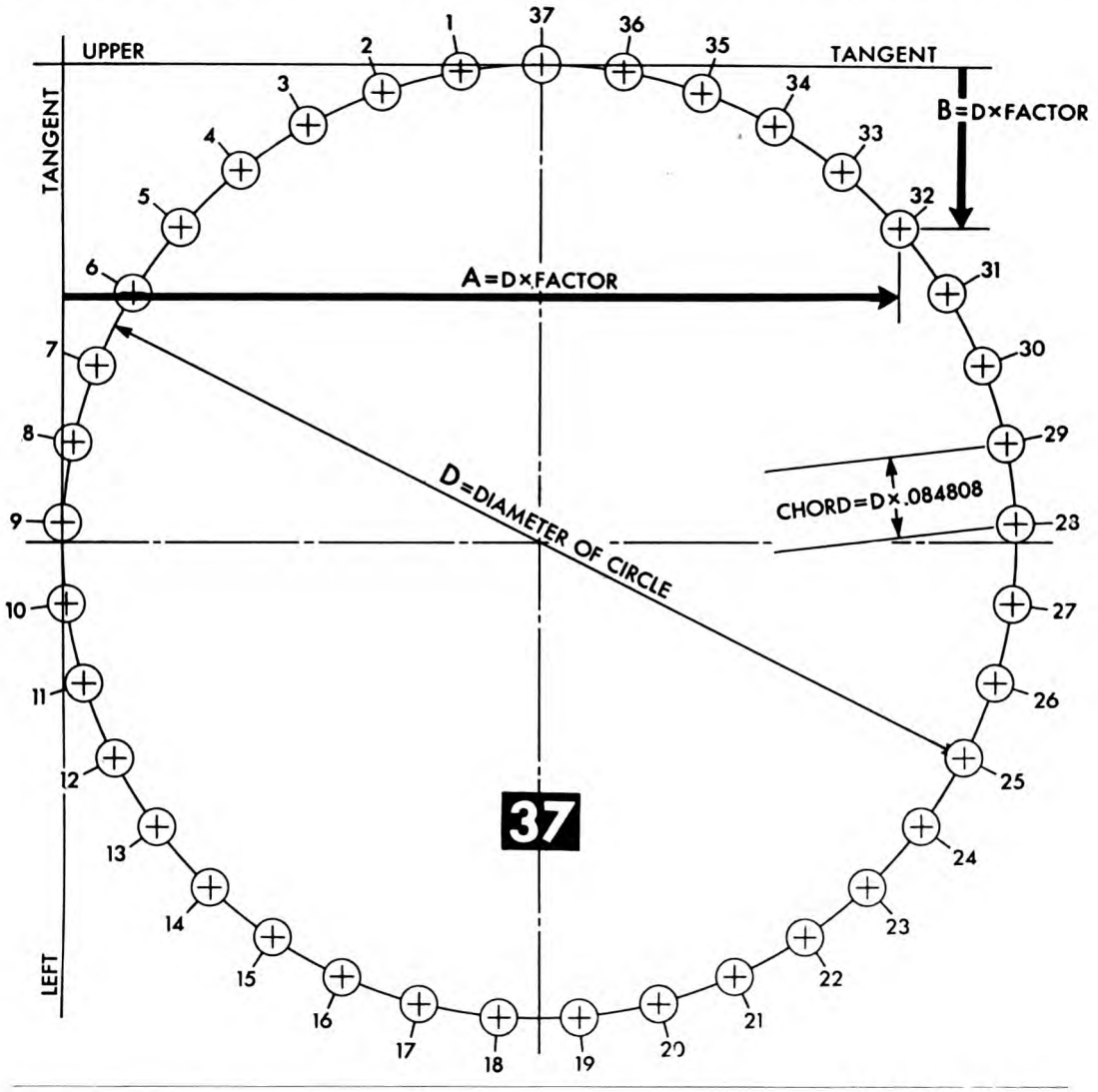


→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
			DEG.	MIN.	SEC.
1 .413176	1 .007596	1	10	0	0
2 .328990	2 .030154	2	20	0	0
3 .250000	3 .066987	3	30	0	0
4 .178606	4 .116978	4	40	0	0
5 .116978	5 .178606	5	50	0	0
6 .066987	6 .250000	6	60	0	0
7 .030154	7 .328990	7	70	0	0
8 .007596	8 .413176	8	80	0	0
9 .000000	9 .500000	9	90	0	0
10 .007596	10 .586824	10	100	0	0

COORDINATE FACTORS AND ANGLES—36 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.030154	11	.671010	11	110	0	0
12	.066987	12	.750000	12	120	0	0
13	.116978	13	.821394	13	130	0	0
14	.178606	14	.883022	14	140	0	0
15	.250000	15	.933013	15	150	0	0
16	.328990	16	.969846	16	160	0	0
17	.413176	17	.992404	17	170	0	0
18	.500000	18	1.000000	18	180	0	0
19	.586824	19	.992404	19	190	0	0
20	.671010	20	.969846	20	200	0	0
21	.750000	21	.933013	21	210	0	0
22	.821394	22	.883022	22	220	0	0
23	.883022	23	.821394	23	230	0	0
24	.933013	24	.750000	24	240	0	0
25	.969846	25	.671010	25	250	0	0
26	.992404	26	.586824	26	260	0	0
27	1.000000	27	.500000	27	270	0	0
28	.992404	28	.413176	28	280	0	0
29	.969846	29	.328990	29	290	0	0
30	.933013	30	.250000	30	300	0	0
31	.883022	31	.178606	31	310	0	0
32	.821394	32	.116978	32	320	0	0
33	.750000	33	.066987	33	330	0	0
34	.671010	34	.030154	34	340	0	0
35	.586824	35	.007596	35	350	0	0
36	.500000	36	.000000	36	360	0	0

37 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

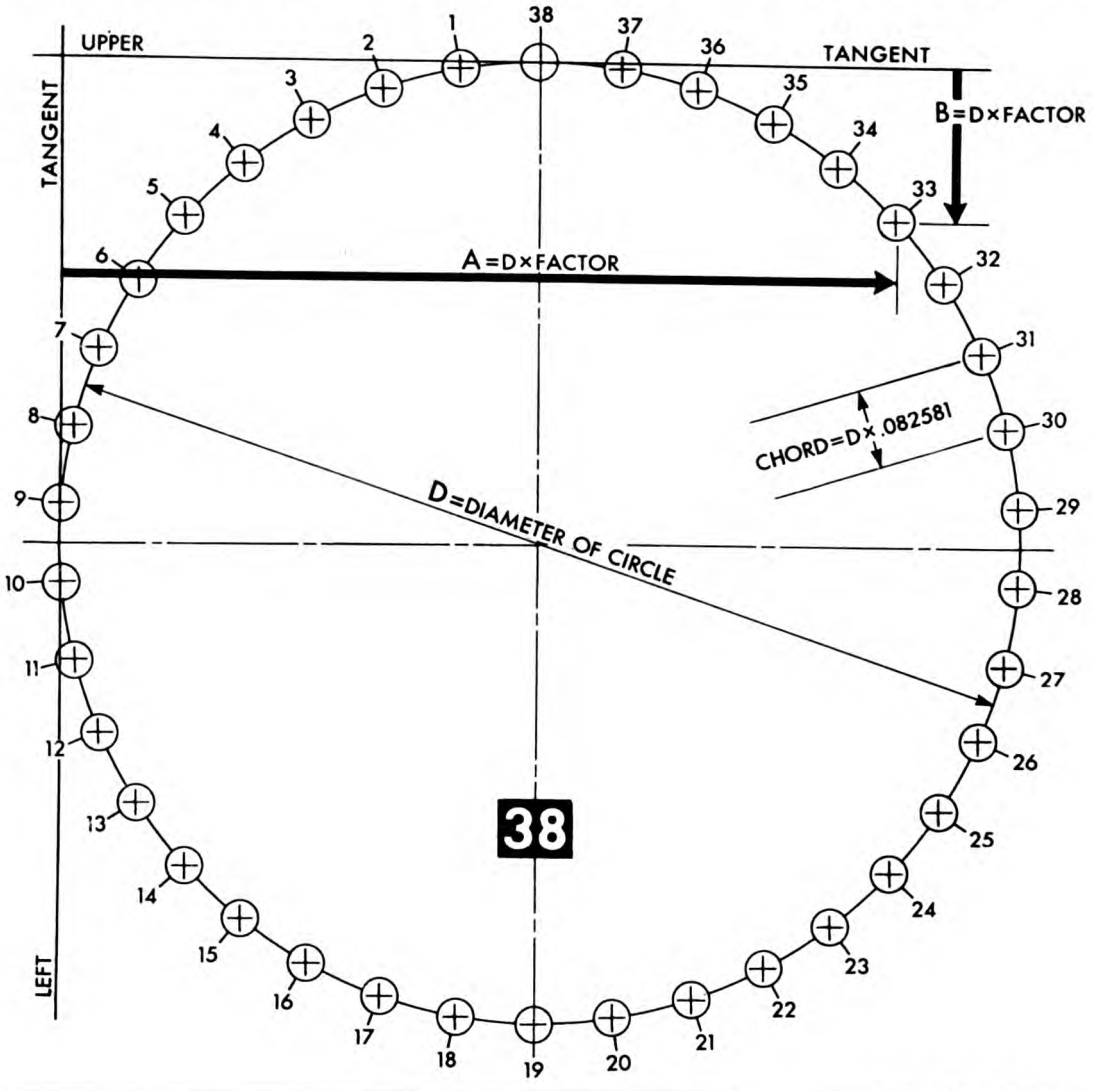


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.415500	1	.007192	1	9	43	47– 1/37
2	.333430	2	.028561	2	19	27	34– 2/37
3	.256153	3	.063493	3	29	11	21– 3/37
4	.185890	4	.110982	4	38	55	8– 4/37
5	.124664	5	.169661	5	48	38	55– 5/37
6	.074235	6	.237846	6	58	22	42– 6/37
7	.036055	7	.313572	7	68	6	29– 7/37
8	.011222	8	.394660	8	77	50	16– 8/37
9	.000451	9	.478779	9	87	34	3– 9/37
10	.004050	10	.563509	10	97	17	50–10/37

COORDINATE FACTORS AND ANGLES—37 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.021917	11	.646411	11	107	1 37–11/37
12	.053537	12	.725102	12	116	45 24–12/37
13	.098001	13	.797317	13	126	29 11–13/37
14	.154031	14	.860978	14	136	12 58–14/37
15	.220013	15	.914255	15	145	56 45–15/37
16	.294049	16	.955614	16	155	40 32–16/37
17	.374011	17	.983866	17	165	24 19–17/37
18	.457597	18	.998199	18	175	8 6–18/37
19	.542403	19	.998199	19	184	51 53–19/37
20	.625989	20	.983866	20	194	35 40–20/37
21	.705951	21	.955614	21	204	19 27–21/37
22	.779987	22	.914255	22	214	3 14–22/37
23	.845969	23	.860978	23	223	47 1–23/37
24	.901999	24	.797317	24	233	30 48–24/37
25	.946463	25	.725102	25	243	14 35–25/37
26	.978083	26	.646411	26	252	58 22–26/37
27	.995950	27	.563509	27	262	42 9–27/37
28	.999549	28	.478779	28	272	25 56–28/37
29	.988778	29	.394660	29	282	9 43–29/37
30	.963945	30	.313572	30	291	53 30–30/37
31	.925765	31	.237846	31	301	37 17–31/37
32	.875336	32	.169661	32	311	21 4–32/37
33	.814110	33	.110982	33	321	4 51–33/37
34	.743847	34	.063493	34	330	48 38–34/37
35	.666570	35	.028561	35	340	32 25–35/37
36	.584500	36	.007192	36	350	16 12–36/37
37	.500000	37	.000000	37	360	0 0

38 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

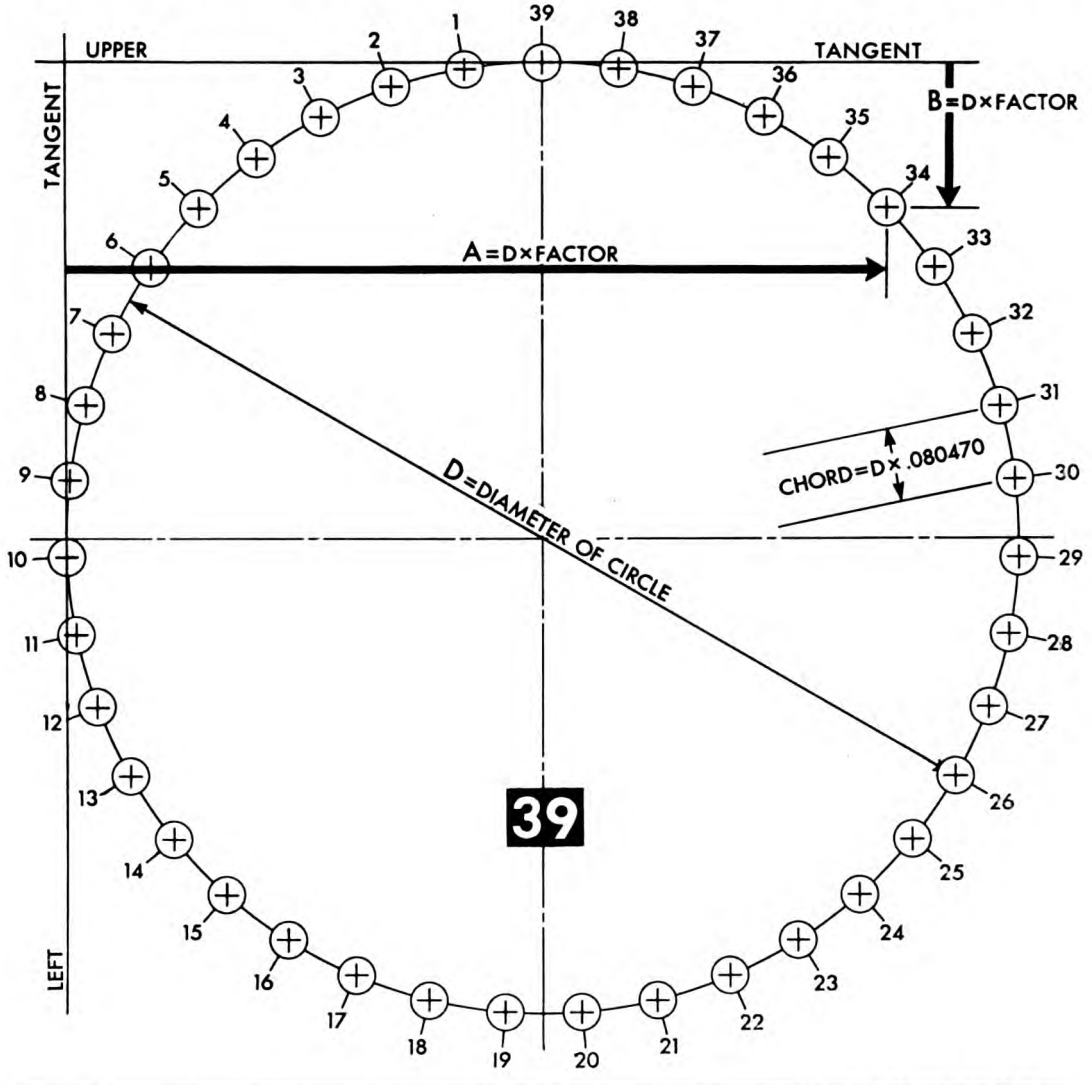


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.417703	1	.006819	1	9	28 25–10/38
2	.337650	2	.027091	2	18	56 50–20/38
3	.262026	3	.060263	3	28	25 15–30/38
4	.192894	4	.105430	4	37	53 41– 2/38
5	.132138	5	.161359	5	47	22 6–12/38
6	.081417	6	.226526	6	56	50 31–22/38
7	.042113	7	.299152	7	66	18 56–32/38
8	.015300	8	.377257	8	75	47 22– 4/38
9	.001708	9	.458710	9	85	15 47–14/38
10	.001708	10	.541290	10	94	44 12–24/38

COORDINATE FACTORS AND ANGLES—38 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.015300	11	.622743	11	104	12 37-34/38
12	.042113	12	.700848	12	113	41 3- 6/38
13	.081417	13	.773474	13	123	9 28-16/38
14	.132138	14	.838641	14	132	37 53-26/38
15	.192894	15	.894570	15	142	6 18-36/38
16	.262026	16	.939737	16	151	34 44- 8/38
17	.337650	17	.972909	17	161	3 9-18/38
18	.417703	18	.993181	18	170	31 34-28/38
19	.500000	19	1.000000	19	180	00 00000000
20	.582297	20	.993181	20	189	28 25-10/38
21	.662350	21	.972909	21	198	56 50-20/38
22	.737974	22	.939737	22	208	25 15-30/38
23	.807106	23	.894570	23	217	53 41- 2/38
24	.867862	24	.838641	24	227	22 6-12/38
25	.918583	25	.773474	25	236	50 31-22/38
26	.957887	26	.700848	26	246	18 56-32/38
27	.984700	27	.622743	27	255	47 22- 4/38
28	.998292	28	.541290	28	265	15 47-14/38
29	.998292	29	.458710	29	274	44 12-24/38
30	.984700	30	.377257	30	284	12 37-34/38
31	.957887	31	.299152	31	293	41 3- 6/38
32	.918583	32	.226526	32	303	9 28-16/38
33	.867862	33	.161359	33	312	37 53-26/38
34	.807106	34	.105430	34	322	6 18-36/38
35	.737974	35	.060263	35	331	34 44- 8/38
36	.662350	36	.027091	36	341	3 9-18/38
37	.582297	37	.006819	37	350	31 34-28/38
38	.500000	38	.000000	38	360	0 0

39 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

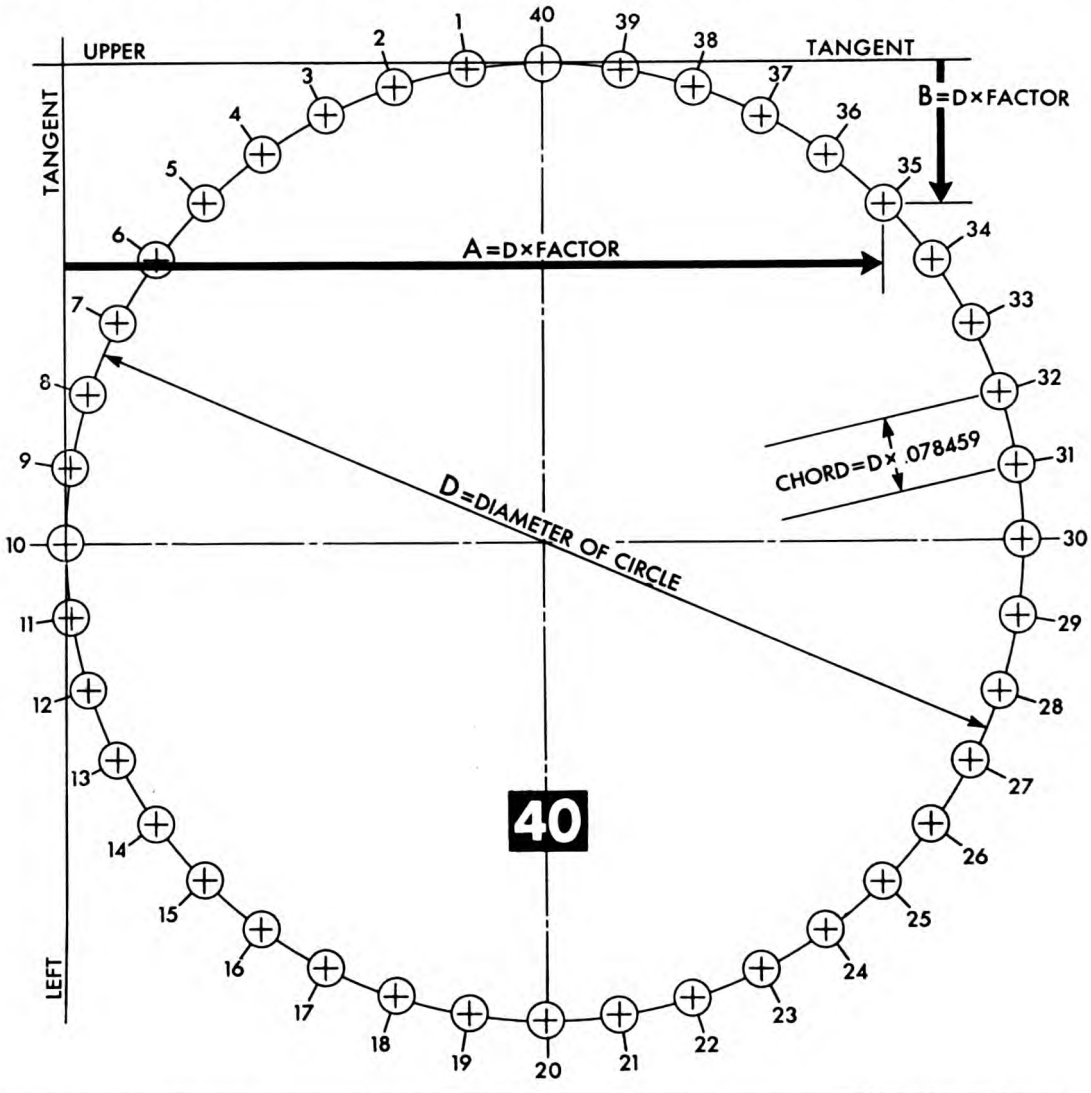


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.419794	1	.006475	1	9	13	50-30/39
2	.341666	2	.025732	2	18	27	41-21/39
3	.267638	3	.057272	3	27	41	32-12/39
4	.199629	4	.100279	4	36	55	23- 3/39
5	.139399	5	.153638	5	46	9	13-33/39
6	.088508	6	.215968	6	55	23	4-24/39
7	.048275	7	.285654	7	64	36	55-15/39
8	.019741	8	.360891	8	73	50	46- 6/39
9	.003646	9	.439732	9	83	4	36-36/39
10	.000406	10	.520133	10	92	18	27-27/39

COORDINATE FACTORS AND ANGLES—39 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.010105	11	.600013	11	101	32	18–18/39
12	.032492	12	.677302	12	110	46	9– 9/39
13	.066987	13	.750000	13	120	00	00000000
14	.112698	14	.816223	14	129	13	50–30/39
15	.168439	15	.874255	15	138	27	41–21/39
16	.232767	16	.922595	16	147	41	32–12/39
17	.304017	17	.959990	17	156	55	23– 3/39
18	.380342	18	.985471	18	166	9	13–33/39
19	.459767	19	.998379	19	175	23	4–24/39
20	.540233	20	.998379	20	184	36	55–15/39
21	.619658	21	.985471	21	193	50	46– 6/39
22	.695983	22	.959990	22	203	4	36–36/39
23	.767233	23	.922595	23	212	18	27–27/39
24	.831561	24	.874255	24	221	32	18–18/39
25	.887302	25	.816223	25	230	46	9– 9/39
26	.933013	26	.750000	26	240	00	00000000
27	.967508	27	.677302	27	249	13	50–30/39
28	.989895	28	.600013	28	258	27	41–21/39
29	.999595	29	.520133	29	267	41	32–12/39
30	.996354	30	.439732	30	276	55	23– 3/39
31	.980259	31	.360891	31	286	9	13–33/39
32	.951725	32	.285654	32	295	23	4–24/39
33	.911492	33	.215968	33	304	36	55–15/39
34	.860601	34	.153638	34	313	50	46– 6/39
35	.800371	35	.100279	35	323	4	36–36/39
36	.732362	36	.057272	36	332	18	27–27/39
37	.658334	37	.025732	37	341	32	18–18/39
38	.580206	38	.006475	38	350	46	9– 9/39
39	.500000	39	.000000	39	360	0	0

40 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

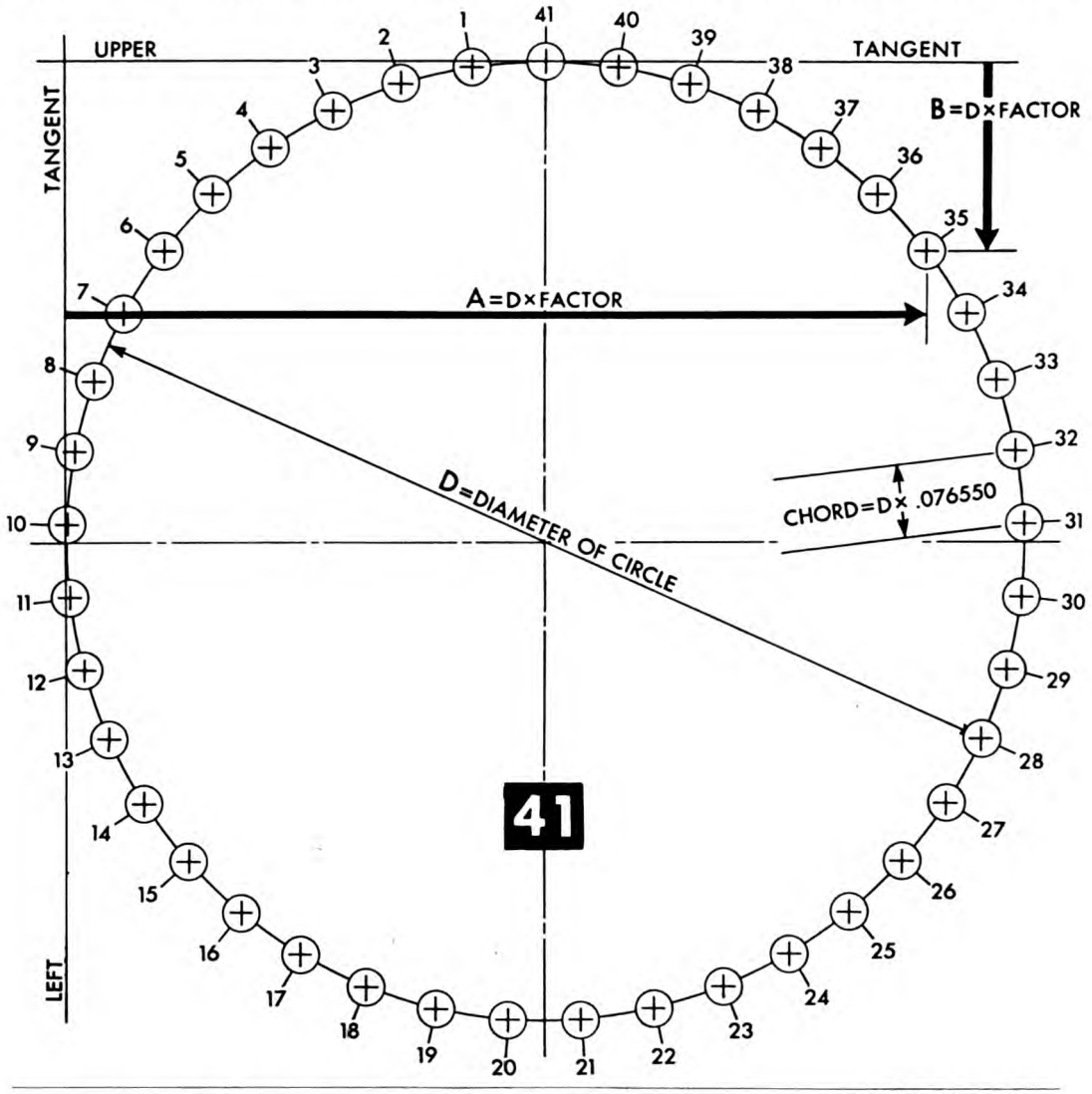


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.421783	1	.006156	1	9	0	0
2	.345492	2	.024472	2	18	0	0
3	.273005	3	.054497	3	27	0	0
4	.206107	4	.095492	4	36	0	0
5	.146447	5	.146447	5	45	0	0
6	.095492	6	.206107	6	54	0	0
7	.054497	7	.273005	7	63	0	0
8	.024472	8	.345492	8	72	0	0
9	.006156	9	.421783	9	81	0	0
10	.000000	10	.500000	10	90	0	0

COORDINATE FACTORS AND ANGLES— 40 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.006156	11	.578217	11	99	0	0
12	.024472	12	.654508	12	108	0	0
13	.054497	13	.726995	13	117	0	0
14	.095492	14	.793893	14	126	0	0
15	.146447	15	.853553	15	135	0	0
16	.206107	16	.904508	16	144	0	0
17	.273005	17	.945503	17	153	0	0
18	.345492	18	.975528	18	162	0	0
19	.421783	19	.993844	19	171	0	0
20	.500000	20	1.000000	20	180	0	0
21	.578217	21	.993844	21	189	0	0
22	.654508	22	.975528	22	198	0	0
23	.726995	23	.945503	23	207	0	0
24	.793893	24	.904508	24	216	0	0
25	.853553	25	.853553	25	225	0	0
26	.904508	26	.793893	26	234	0	0
27	.945503	27	.726995	27	243	0	0
28	.975528	28	.654508	28	252	0	0
29	.993844	29	.578217	29	261	0	0
30	1.000000	30	.500000	30	270	0	0
31	.993844	31	.421783	31	279	0	0
32	.975528	32	.345492	32	288	0	0
33	.945503	33	.273005	33	297	0	0
34	.904508	34	.206107	34	306	0	0
35	.853553	35	.146447	35	315	0	0
36	.793893	36	.095492	36	324	0	0
37	.726995	37	.054497	37	333	0	0
38	.654508	38	.024472	38	342	0	0
39	.578217	39	.006156	39	351	0	0
40	.500000	40	.000000	40	360	0	0

41 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

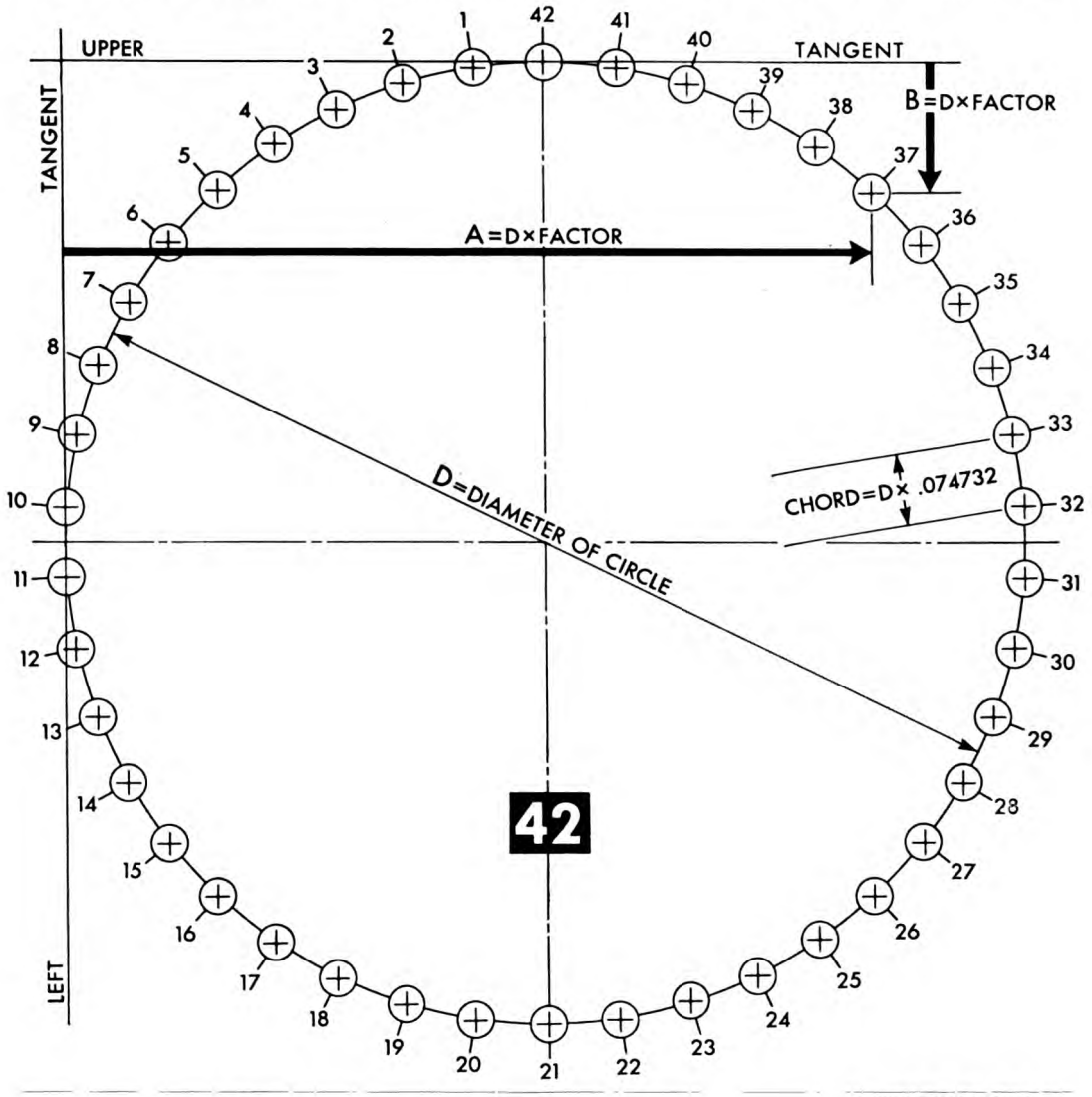


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.423675	1	.005860	1	8	46	49-31/41
2	.349140	2	.023302	2	17	33	39-21/41
3	.278140	3	.051917	3	26	20	29-11/41
4	.212341	4	.091035	4	35	7	19- 1/41
5	.153284	5	.139739	5	43	54	8-32/41
6	.102354	6	.196887	6	52	40	58-22/41
7	.060744	7	.261140	7	61	27	48-12/41
8	.029430	8	.330992	8	70	14	38- 2/41
9	.009146	9	.404804	9	79	1	27-33/41
10	.000367	10	.480849	10	87	48	17-23/41

COORDINATE FACTORS AND ANGLES—41 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.003299	11	.557342	11	96	35	7-13/41
12	.017873	12	.632491	12	105	21	57- 3/41
13	.043748	13	.704534	13	114	8	46-34/41
14	.080317	14	.771784	14	122	55	36-24/41
15	.126723	15	.832663	15	131	42	26-14/41
16	.181879	16	.885745	16	140	29	16- 4/41
17	.244491	17	.929785	17	149	16	5-35/41
18	.313091	18	.963751	18	158	2	55-25/41
19	.386073	19	.986848	19	166	49	45-15/41
20	.461725	20	.998533	20	175	36	35- 5/41
21	.538275	21	.998533	21	184	23	24-36/41
22	.613927	22	.986848	22	193	10	14-26/41
23	.686909	23	.963751	23	201	57	4-16/41
24	.755509	24	.929785	24	210	43	54- 6/41
25	.818121	25	.885745	25	219	30	43-37/41
26	.873277	26	.832663	26	228	17	33-27/41
27	.919683	27	.771784	27	237	4	23-17/41
28	.956252	28	.704534	28	245	51	13- 7/41
29	.982127	29	.632491	29	254	38	2-38/41
30	.996701	30	.557342	30	263	24	52-28/41
31	.999633	31	.480849	31	272	11	42-18/41
32	.990854	32	.404804	32	280	58	32- 8/41
33	.970570	33	.330992	33	289	45	21-39/41
34	.939256	34	.261140	34	298	32	11-29/41
35	.897646	35	.196887	35	307	19	1-19/41
36	.846716	36	.139739	36	316	5	51- 9/41
37	.787659	37	.091035	37	324	52	40-40/41
38	.721860	38	.051917	38	333	39	30-30/41
39	.650860	39	.023302	39	342	26	20-20/41
40	.576325	40	.005860	40	351	13	10-10/41
41	.500000	41	.000000	41	360	0	0

42 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

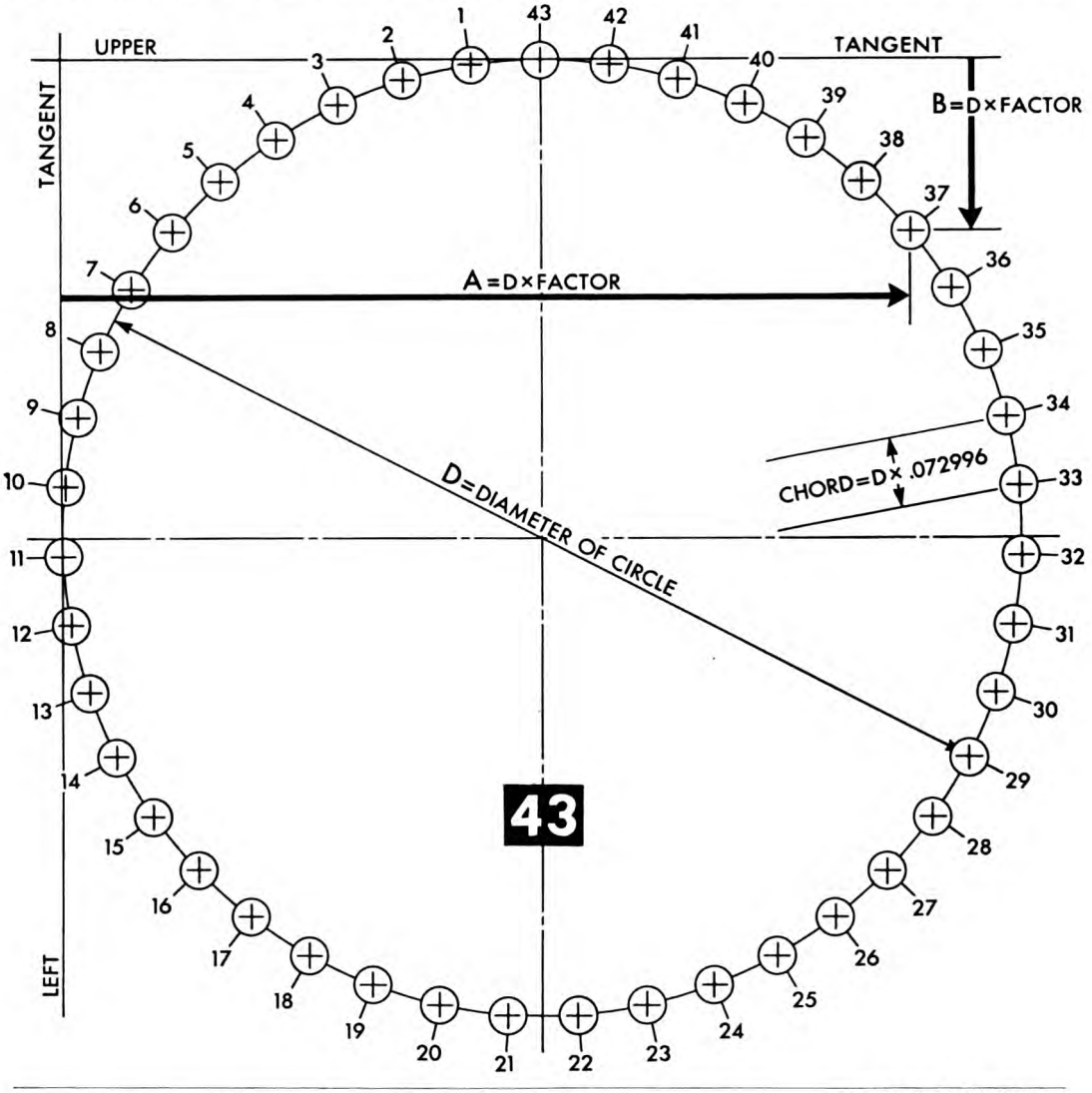


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.425479	1	.005585	1	8	34	17- 6/42
2	.352622	2	.022214	2	17	8	34-12/42
3	.283058	3	.049516	3	25	42	51-18/42
4	.218340	4	.086881	4	34	17	8-24/42
5	.159914	5	.133474	5	42	51	25-30/42
6	.109084	6	.188255	6	51	25	42-36/42
7	.066987	7	.250000	7	60	00	00000000
8	.034563	8	.317329	8	68	34	17- 6/42
9	.012536	9	.388740	9	77	8	34-12/42
10	.001398	10	.462635	10	85	42	51-18/42

COORDINATE FACTORS AND ANGLES—42 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.001398	11	.537365	11	94	17	8-24/42
12	.012536	12	.611260	12	102	51	25-30/42
13	.034563	13	.682671	13	111	25	42-36/42
14	.066987	14	.750000	14	120	00	00000000
15	.109084	15	.811745	15	128	34	17- 6/42
16	.159914	16	.866526	16	137	8	34-12/42
17	.218340	17	.913119	17	145	42	51-18/42
18	.283058	18	.950484	18	154	17	8-24/42
19	.352622	19	.977786	19	162	51	25-30/42
20	.425479	20	.994415	20	171	25	42-36/42
21	.500000	21	1.000000	21	180	00	00000000
22	.574521	22	.994415	22	188	34	17- 6/42
23	.647378	23	.977786	23	197	8	34-12/42
24	.716942	24	.950484	24	205	42	51-18/42
25	.781660	25	.913119	25	214	17	8-24/42
26	.840086	26	.866526	26	222	51	25-30/42
27	.890916	27	.811745	27	231	25	42-36/42
28	.933013	28	.750000	28	240	00	00000000
29	.965437	29	.682671	29	248	34	17- 6/42
30	.987464	30	.611260	30	257	8	34-12/42
31	.998602	31	.537365	31	265	42	51-18/42
32	.998602	32	.462635	32	274	17	8-24/42
33	.987464	33	.388740	33	282	51	25-30/42
34	.965437	34	.317329	34	291	25	42-36/42
35	.933013	35	.250000	35	300	00	00000000
36	.890916	36	.188255	36	308	34	17- 6/42
37	.840086	37	.133474	37	317	8	34-12/42
38	.781660	38	.086881	38	325	42	51-18/42
39	.716942	39	.049516	39	334	17	8-24/42
40	.647378	40	.022214	40	342	51	25-30/42
41	.574521	41	.005585	41	351	25	42-36/42
42	.500000	42	.000000	42	360	0	0

43 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

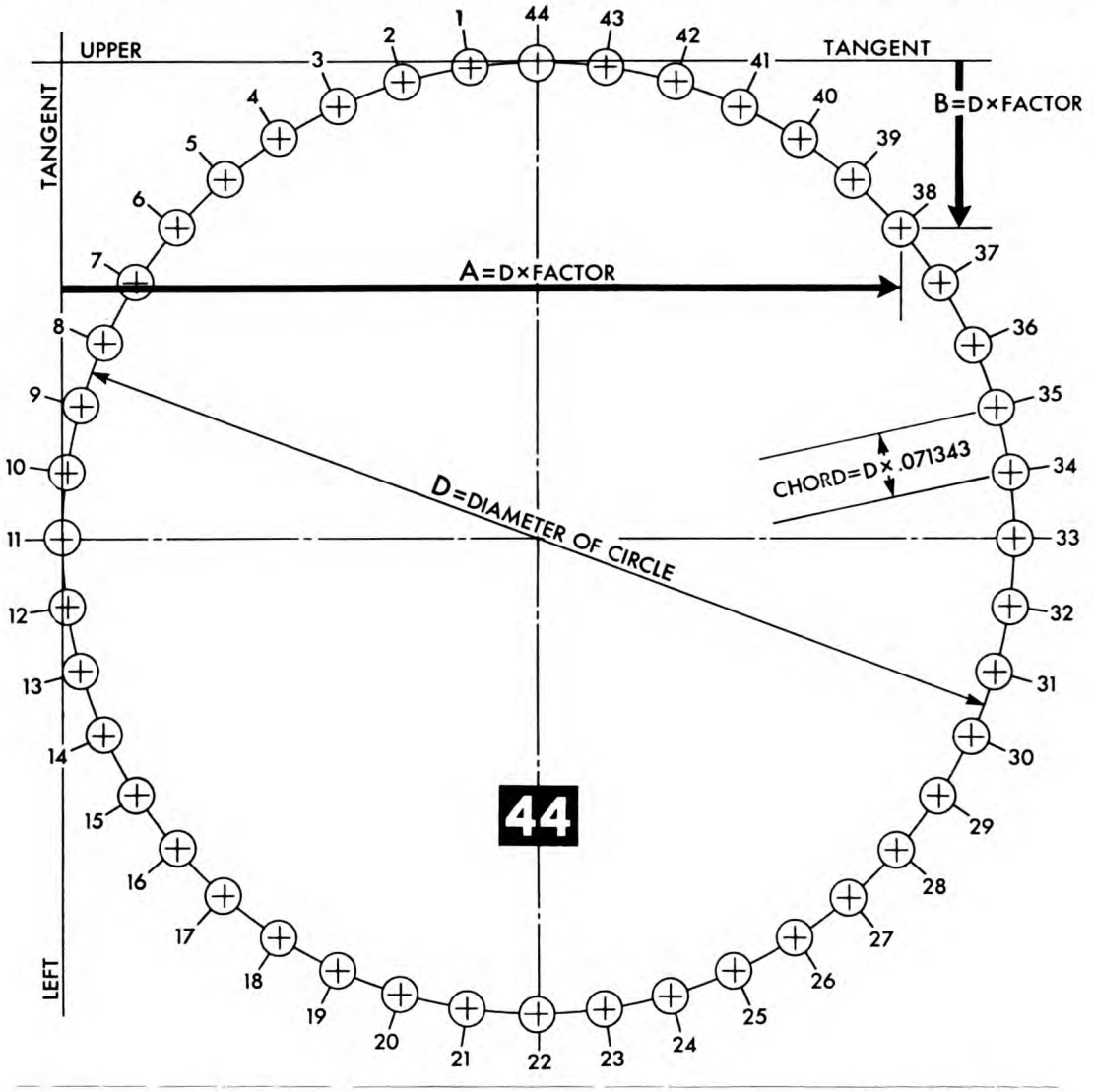


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.427199	1	.005328	1	8	22 19–23/43
2	.355950	2	.021200	2	16	44 39– 3/43
3	.287772	3	.047276	3	25	6 58–26/43
4	.224116	4	.083001	4	33	29 18– 6/43
5	.166342	5	.127614	5	41	51 37–29/43
6	.115676	6	.180163	6	50	13 57– 9/43
7	.073203	7	.239530	7	58	36 16–32/43
8	.039827	8	.304448	8	66	58 36–12/43
9	.016258	9	.373533	9	75	20 55–35/43
10	.003000	10	.445314	10	83	43 15–15/43

COORDINATE FACTORS AND ANGLES—43 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.000334	11	.518261	11	92	5 34-38/43
12	.008317	12	.590818	12	100	27 54-18/43
13	.026780	13	.661440	13	108	50 13-41/43
14	.055329	14	.728621	14	117	12 33-21/43
15	.093355	15	.790929	15	125	34 53- 1/43
16	.140048	16	.847037	16	133	57 12-24/43
17	.194413	17	.895748	17	142	19 32- 4/43
18	.255291	18	.936025	18	150	41 51-27/43
19	.321384	19	.967008	19	159	4 11- 7/43
20	.391285	20	.988038	20	167	26 30-30/43
21	.463502	21	.998666	21	175	48 50-10/43
22	.536498	22	.998666	22	184	11 9-33/43
23	.608715	23	.988038	23	192	33 29-13/43
24	.678616	24	.967008	24	200	55 48-36/43
25	.744709	25	.936025	25	209	18 8-16/43
26	.805587	26	.895748	26	217	40 27-39/43
27	.859952	27	.847037	27	226	2 47-19/43
28	.906645	28	.790929	28	234	25 6-42/43
29	.944671	29	.728621	29	242	47 26-22/43
30	.973220	30	.661440	30	251	9 46- 2/43
31	.991683	31	.590818	31	259	32 5-25/43
32	.999666	32	.518261	32	267	54 25- 5/43
33	.997000	33	.445314	33	276	16 44-28/43
34	.983742	34	.373533	34	284	39 4- 8/43
35	.960173	35	.304448	35	293	1 23-31/43
36	.926797	36	.239530	36	301	23 43-11/43
37	.884324	37	.180163	37	309	46 2-34/43
38	.833658	38	.127614	38	318	8 22-14/43
39	.775884	39	.083001	39	326	30 41-37/43
40	.712228	40	.047276	40	334	53 1-17/43
41	.644050	41	.021200	41	343	15 20-40/43
42	.572801	42	.005328	42	351	37 40-20/43
43	.500000	43	.000000	43	360	0 0

44 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

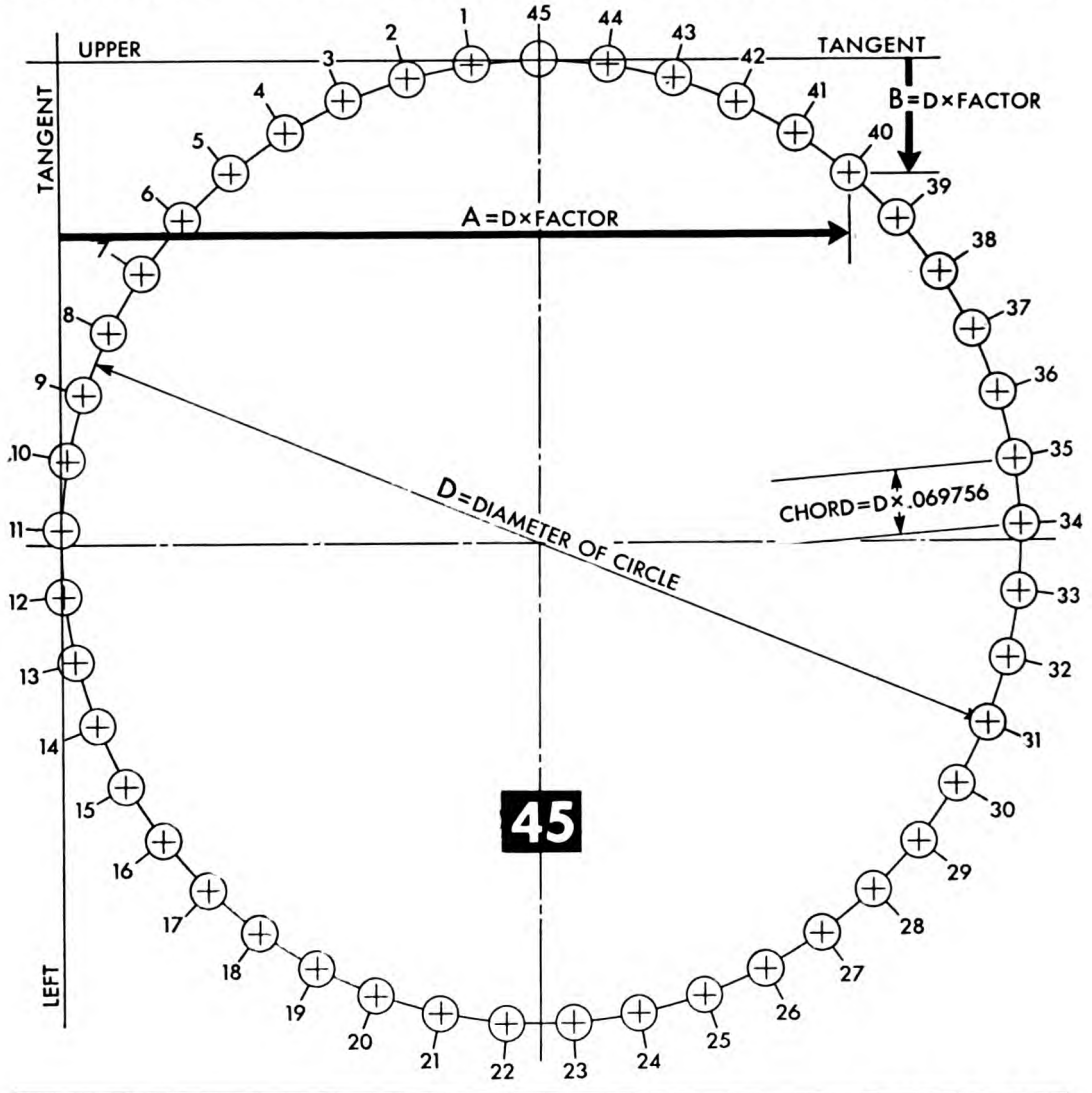


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.428843	1	.005089	1	8	10 54-24/44
2	.359134	2	.020254	2	16	21 49- 4/44
3	.292293	3	.045184	3	24	32 43-28/44
4	.229680	4	.079373	4	32	43 38- 8/44
5	.172570	5	.122125	5	40	54 32-32/44
6	.122125	6	.172570	6	49	5 27-12/44
7	.079373	7	.229680	7	57	16 21-36/44
8	.045184	8	.292293	8	65	27 16-16/44
9	.020254	9	.359134	9	73	38 10-40/44
10	.005089	10	.428843	10	81	49 5-20/44

COORDINATE FACTORS AND ANGLES—44 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.000000	11	.500000	11	90	00	00000000
12	.005089	12	.571157	12	98	10	54–24/44
13	.020254	13	.640866	13	106	21	49– 4/44
14	.045184	14	.707708	14	114	32	43–28/44
15	.079373	15	.770320	15	122	43	38– 8/44
16	.122125	16	.827430	16	130	54	32–32/44
17	.172570	17	.877875	17	139	5	27–12/44
18	.229680	18	.920627	18	147	16	21–36/44
19	.292293	19	.954816	19	155	27	16–16/44
20	.359134	20	.979746	20	163	38	10–40/44
21	.428843	21	.994911	21	171	49	5–20/44
22	.500000	22	1.000000	22	180	00	00000000
23	.571157	23	.994911	23	188	10	54–24/44
24	.640866	24	.979746	24	196	21	49– 4/44
25	.707708	25	.954816	25	204	32	43–28/44
26	.770320	26	.920627	26	212	43	38– 8/44
27	.827430	27	.877875	27	220	54	32–32/44
28	.877875	28	.827430	28	229	5	27–12/44
29	.920627	29	.770320	29	237	16	21–36/44
30	.954816	30	.707708	30	245	27	16–16/44
31	.979746	31	.640866	31	253	38	10–40/44
32	.994911	32	.571157	32	261	49	5–20/44
33	1.000000	33	.500000	33	270	00	00000000
34	.994911	34	.428843	34	278	10	54–24/44
35	.979746	35	.359134	35	286	21	49– 4/44
36	.954816	36	.292293	36	294	32	43–28/44
37	.920627	37	.229680	37	302	43	38– 8/44
38	.877875	38	.172570	38	310	54	32–32/44
39	.827430	39	.122125	39	319	5	27–12/44
40	.770320	40	.079373	40	327	16	21–36/44
41	.707708	41	.045184	41	335	27	16–16/44
42	.640866	42	.020254	42	343	38	10–40/44
43	.571157	43	.005089	43	351	49	5–20/44
44	.500000	44	000000	44	360	0	0

45 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

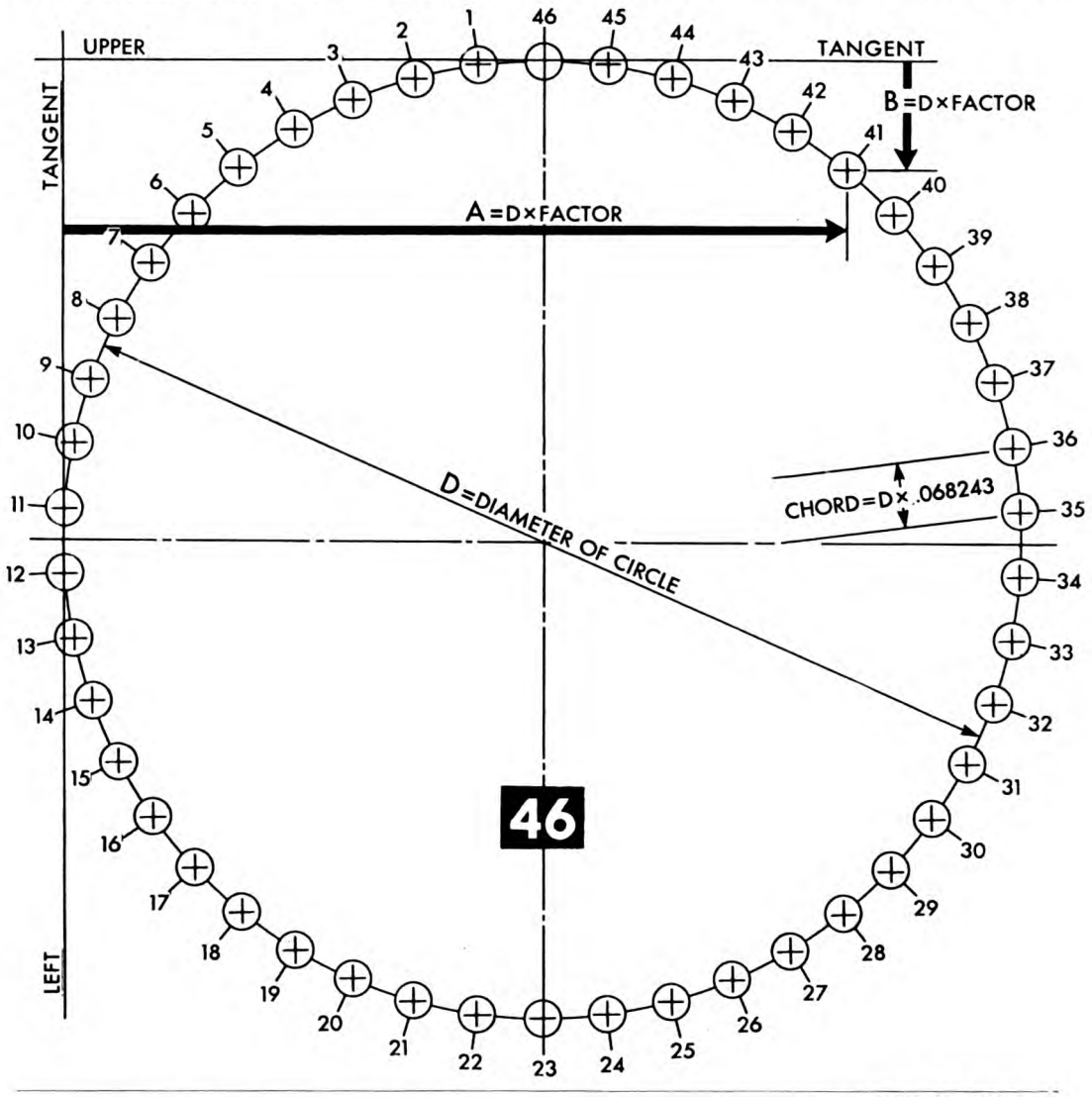


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.430413	1	.004866	1	8	0	0
2	.362181	2	.019369	2	16	0	0
3	.296632	3	.043227	3	24	0	0
4	.235040	4	.075976	4	32	0	0
5	.178606	5	.116978	5	40	0	0
6	.128428	6	.165435	6	48	0	0
7	.085481	7	.220404	7	56	0	0
8	.050603	8	.280814	8	64	0	0
9	.024472	9	.345492	9	72	0	0
10	.007596	10	.413176	10	80	0	0

COORDINATE FACTORS AND ANGLES—45 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.000305	11	.482550	11	88	0	0
12	.002739	12	.552264	12	96	0	0
13	.014852	13	.620961	13	104	0	0
14	.036408	14	.687303	14	112	0	0
15	.066987	15	.750000	15	120	0	0
16	.105995	16	.807831	16	128	0	0
17	.152671	17	.859670	17	136	0	0
18	.206107	18	.904508	18	144	0	0
19	.265264	19	.941474	19	152	0	0
20	.328990	20	.969846	20	160	0	0
21	.396044	21	.989074	21	168	0	0
22	.465122	22	.998782	22	176	0	0
23	.534878	23	.998782	23	184	0	0
24	.603956	24	.989074	24	192	0	0
25	.671010	25	.969846	25	200	0	0
26	.734736	26	.941474	26	208	0	0
27	.793893	27	.904508	27	216	0	0
28	.847329	28	.859670	28	224	0	0
29	.894005	29	.807831	29	232	0	0
30	.933013	30	.750000	30	240	0	0
31	.963592	31	.687303	31	248	0	0
32	.985148	32	.620961	32	256	0	0
33	.997261	33	.552264	33	264	0	0
34	.999695	34	.482550	34	272	0	0
35	.992404	35	.413176	35	280	0	0
36	.975528	36	.345492	36	288	0	0
37	.949397	37	.280814	37	296	0	0
38	.914519	38	.220404	38	304	0	0
39	.871572	39	.165435	39	312	0	0
40	.821394	40	.116978	40	320	0	0
41	.764960	41	.075976	41	328	0	0
42	.703368	42	.043227	42	336	0	0
43	.637819	43	.019369	43	344	0	0
44	.569587	44	.004866	44	352	0	0
45	.500000	45	.000000	45	360	0	0

46 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

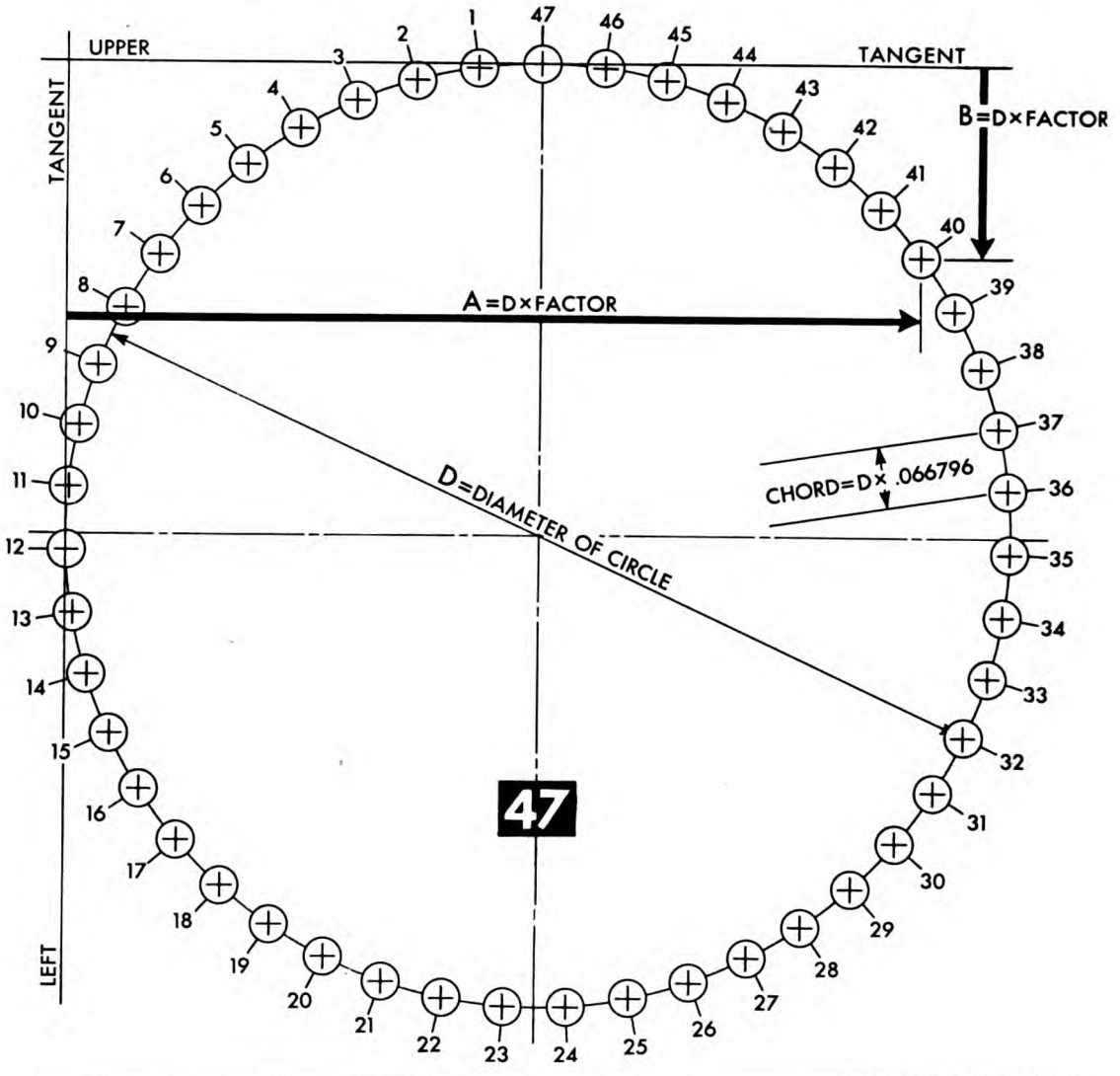


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.431917	1	.004657	1	7	49 33-42/46
2	.365102	2	.018541	2	15	39 7-38/46
3	.300803	3	.041394	3	23	28 41-34/46
4	.240208	4	.072790	4	31	18 15-30/46
5	.184456	5	.112144	5	39	7 49-26/46
6	.134582	6	.158723	6	46	57 23-22/46
7	.091515	7	.211660	7	54	46 57-18/46
8	.056057	8	.269967	8	62	36 31-14/46
9	.028870	9	.332560	9	70	26 5-10/46
10	.010458	10	.398272	10	78	15 39- 6/46

COORDINATE FACTORS AND ANGLES—46 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.001166	11	.465879	11	86	5 13– 2/46
12	.001166	12	.534121	12	93	54 46–44/46
13	.010458	13	.601728	13	101	44 20–40/46
14	.028870	14	.667440	14	109	33 54–36/46
15	.056057	15	.730033	15	117	23 28–32/46
16	.091515	16	.788340	16	125	13 2–28/46
17	.134582	17	.841277	17	133	2 36–24/46
18	.184456	18	.887856	18	140	52 10–20/46
19	.240208	19	.927210	19	148	41 44–16/46
20	.300803	20	.958606	20	156	31 18–12/46
21	.365102	21	.981459	21	164	20 52– 8/46
22	.431917	22	.995343	22	172	10 26– 4/46
23	.500000	23	1.000000	23	180	00 00000000
24	.568083	24	.995343	24	187	49 33–42/46
25	.634898	25	.981459	25	195	39 7–38/46
26	.699197	26	.958606	26	203	28 41–34/46
27	.759792	27	.927210	27	211	18 15–30/46
28	.815544	28	.887856	28	219	7 49–26/46
29	.865418	29	.841277	29	226	57 23–22/46
30	.908485	30	.788340	30	234	46 57–18/46
31	.943943	31	.730033	31	242	36 31–14/46
32	.971130	32	.667440	32	250	26 5–10/46
33	.989542	33	.601728	33	258	15 39– 6/46
34	.998834	34	.534121	34	266	5 13– 2/46
35	.998834	35	.465879	35	273	54 46–44/46
36	.989542	36	.398272	36	281	44 20–40/46
37	.971130	37	.332560	37	289	33 54–36/46
38	.943943	38	.269967	38	297	23 28–32/46
39	.908485	39	.211660	39	305	13 2–28/46
40	.865418	40	.158723	40	313	2 36–24/46
41	.815544	41	.112144	41	320	52 10–20/46
42	.759792	42	.072790	42	328	41 44–16/46
43	.699197	43	.041394	43	336	31 18–12/46
44	.634898	44	.018541	44	344	20 52– 8/46
45	.568083	45	.004657	45	352	10 26– 4/46
46	.500000	46	.000000	46	360	0 0

47 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

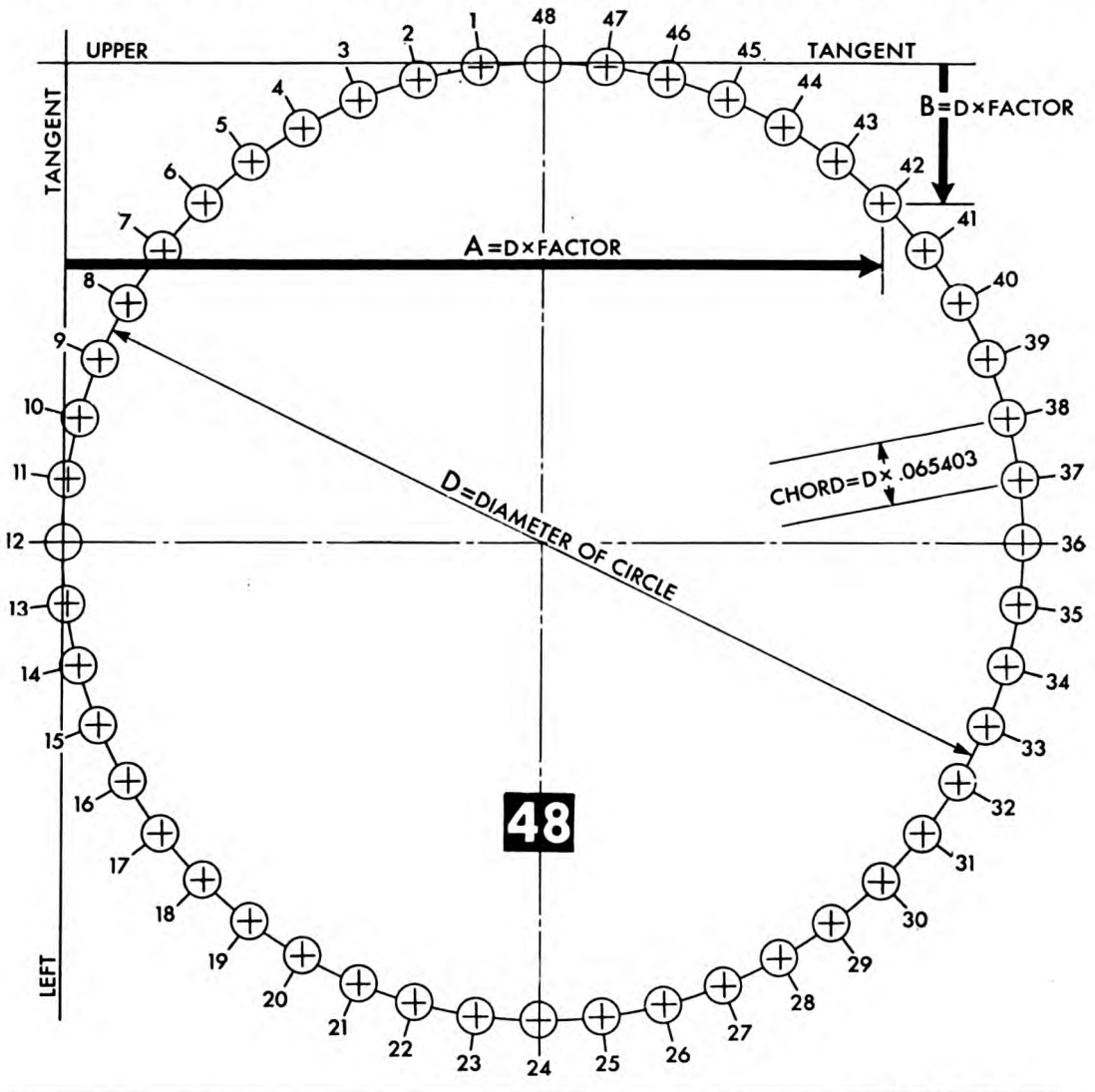


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.433357	1	.004461	1	7	39	34–22/47
2	.367902	2	.017765	2	15	19	8–44/47
3	.304806	3	.039675	3	22	58	43–19/47
4	.245192	4	.069799	4	30	38	17–41/47
5	.190125	5	.107600	5	38	17	52–16/47
6	.140588	6	.152404	6	45	57	26–38/47
7	.097465	7	.203410	7	53	37	1–13/47
8	.061525	8	.259709	8	61	16	35–35/47
9	.033410	9	.320296	9	68	56	10–10/47
10	.013621	10	.384090	10	76	35	44–32/47

COORDINATE FACTORS AND ANGLES—47 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.002511	11	.449952	11	84	15	19- 7/47
12	.000279	12	.516707	12	91	54	53-29/47
13	.006965	13	.583165	13	99	34	28- 4/47
14	.022449	14	.648138	14	107	14	2-26/47
15	.046455	15	.710468	15	114	53	37- 1/47
16	.078554	16	.769041	16	122	33	11-23/47
17	.118174	17	.822814	17	130	12	45-45/47
18	.164608	18	.870826	18	137	52	20-20/47
19	.217026	19	.912221	19	145	31	54-42/47
20	.274495	20	.946259	20	153	11	29-17/47
21	.335988	21	.972335	21	160	51	3-39/47
22	.400407	22	.989981	22	168	30	38-14/47
23	.466604	23	.998883	23	176	10	12-36/47
24	.533396	24	.998883	24	183	49	47-11/47
25	.599593	25	.989981	25	191	29	21-33/47
26	.664012	26	.972335	26	199	8	56- 8/47
27	.725505	27	.946259	27	206	48	30-30/47
28	.782974	28	.912221	28	214	28	5- 5/47
29	.835392	29	.870826	29	222	7	39-27/47
30	.881826	30	.822814	30	229	47	14- 2/47
31	.921446	31	.769041	31	237	26	48-24/47
32	.953545	32	.710468	32	245	6	22-46/47
33	.977551	33	.648138	33	252	45	57-21/47
34	.993035	34	.583165	34	260	25	31-43/47
35	.999721	35	.516707	35	268	5	6-18/47
36	.997489	36	.449952	36	275	44	40-40/47
37	.986379	37	.384090	37	283	24	15-15/47
38	.966590	38	.320296	38	291	3	49-37/47
39	.938475	39	.259709	39	298	43	24-12/47
40	.902535	40	.203410	40	306	22	58-34/47
41	.859412	41	.152404	41	314	2	33- 9/47
42	.809875	42	.107600	42	321	42	7-31/47
43	.754808	43	.069799	43	329	21	42- 6/47
44	.695194	44	.039675	44	337	1	16-28/47
45	.632098	45	.017765	45	344	40	51- 3/47
46	.566643	46	.004461	46	352	20	25-25/47
47	.500000	47	.000000	47	360	0	0

48 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

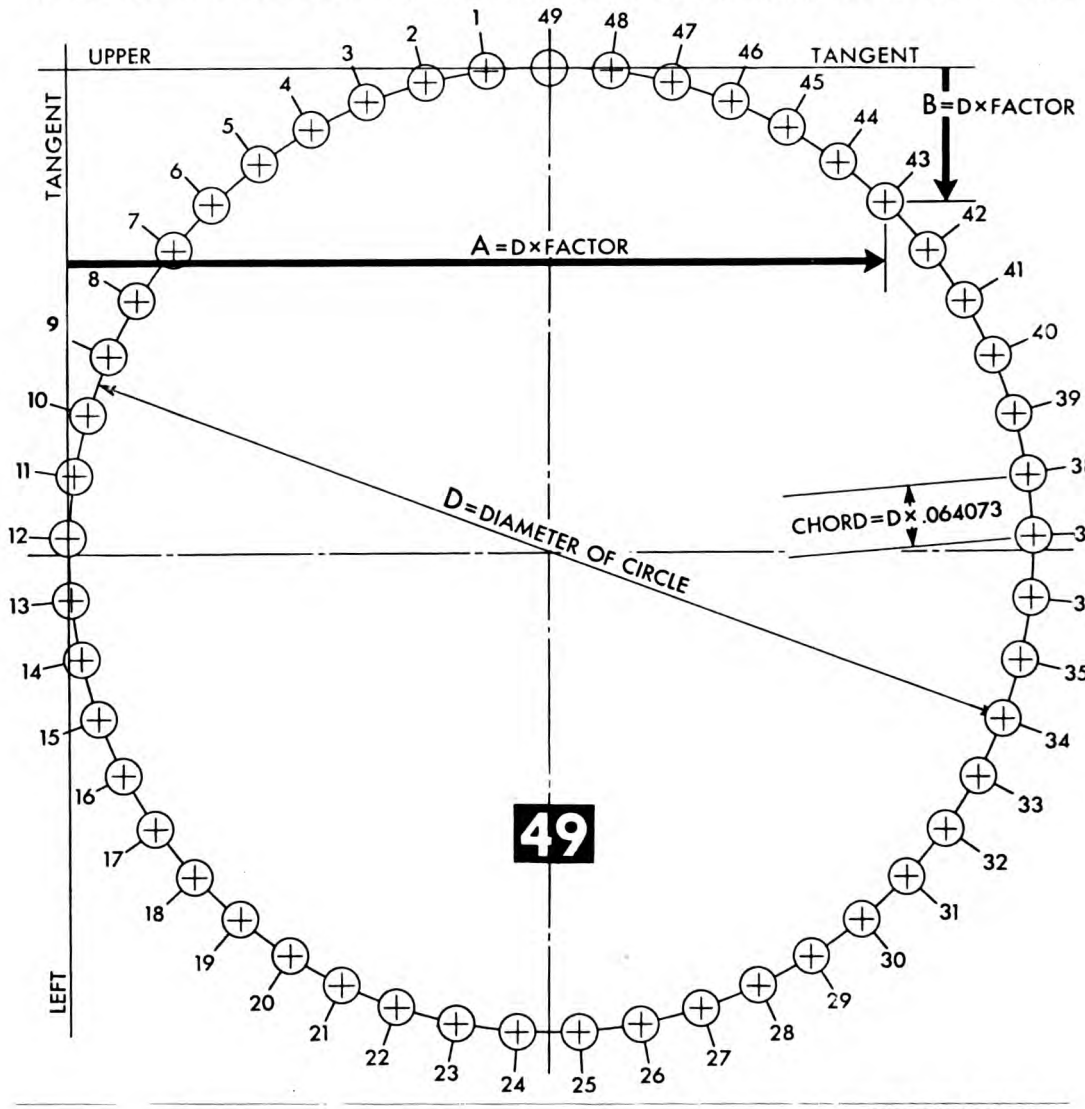


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.434737	1	.004278	1	7	30	0
2	.370590	2	.017037	2	15	00	0
3	.308658	3	.038060	3	22	30	0
4	.250000	4	.066987	4	30	00	0
5	.195619	5	.103323	5	37	30	0
6	.146447	6	.146447	6	45	00	0
7	.103323	7	.195619	7	52	30	0
8	.066987	8	.250000	8	60	00	0
9	.038060	9	.308658	9	67	30	0
10	.017037	10	.370590	10	75	00	0

COORDINATE FACTORS AND ANGLES—48 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.004278	11	.434737	11	82	30	0
12	.000000	12	.500000	12	90	00	0
13	.004278	13	.565263	13	97	30	0
14	.017037	14	.629410	14	105	00	0
15	.038060	15	.691342	15	112	30	0
16	.066987	16	.750000	16	120	00	0
17	.103323	17	.804381	17	127	30	0
18	.146447	18	.853553	18	135	00	0
19	.195619	19	.896677	19	142	30	0
20	.250000	20	.933013	20	150	00	0
21	.308658	21	.961940	21	157	30	0
22	.370590	22	.982963	22	165	00	0
23	.434737	23	.995722	23	172	30	0
24	.500000	24	1.000000	24	180	00	0
25	.565263	25	.995722	25	187	30	0
26	.629410	26	.982963	26	195	00	0
27	.691342	27	.961940	27	202	30	0
28	.750000	28	.933013	28	210	00	0
29	.804381	29	.896677	29	217	30	0
30	.853553	30	.853553	30	225	00	0
31	.896677	31	.804381	31	232	30	0
32	.933013	32	.750000	32	240	00	0
33	.961940	33	.691342	33	247	30	0
34	.982963	34	.629410	34	255	00	0
35	.995722	35	.565263	35	262	30	0
36	1.000000	36	.500000	36	270	00	0
37	.995722	37	.434737	37	277	30	0
38	.982963	38	.370590	38	285	00	0
39	.961940	39	.308658	39	292	30	0
40	.933013	40	.250000	40	300	00	0
41	.896677	41	.195619	41	307	30	0
42	.853553	42	.146447	42	315	00	0
43	.804381	43	.103323	43	322	30	0
44	.750000	44	.066987	44	330	00	0
45	.691342	45	.038060	45	337	30	0
46	.629410	46	.017037	46	345	00	0
47	.565263	47	.004278	47	352	30	0
48	.500000	48	.000000	48	360	0	0

49 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

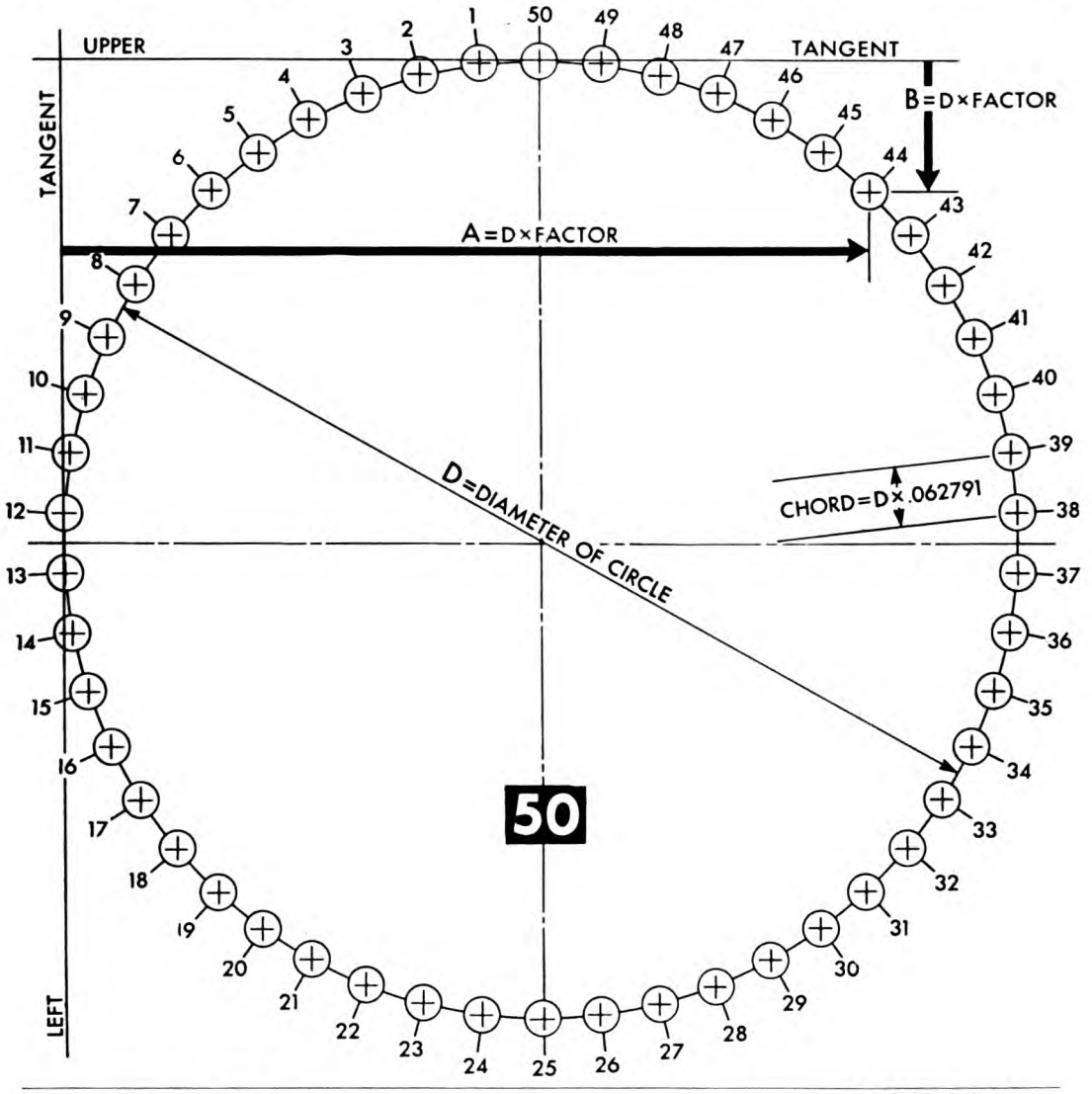


→ FACTOR FOR "A"		↓ FACTOR FOR "B"			ANGLE OF HOLE DEG.	MIN.	SEC.
1	.436061	1	.004105	1	7	20	48–48/49
2	.373175	2	.016353	2	14	41	37–47/49
3	.312367	3	.036542	3	22	2	26–46/49
4	.254641	4	.064341	4	29	23	15–45/49
5	.200945	5	.099293	5	36	44	4–44/49
6	.152159	6	.140825	6	44	4	53–43/49
7	.109084	7	.188255	7	51	25	42–42/49
8	.072429	8	.240804	8	58	46	31–41/49
9	.042794	9	.297608	9	66	7	20–40/49
10	.020666	10	.357736	10	73	28	9–39/49

COORDINATE FACTORS AND ANGLES—49 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
11	.006409	11	.420200	11	80	48 58-38/49
12	.000257	12	.483972	12	88	9 47-37/49
13	.002310	13	.548012	13	95	30 36-36/49
14	.012536	14	.611260	14	102	51 25-35/49
15	.030766	15	.672682	15	110	12 14-34/49
16	.056700	16	.731269	16	117	33 3-33/49
17	.089914	17	.786058	17	124	53 52-32/49
18	.129860	18	.836150	18	132	14 41-31/49
19	.175886	19	.880723	19	139	35 30-30/49
20	.227233	20	.919044	20	146	56 19-29/49
21	.283058	21	.950484	21	154	17 8-28/49
22	.342447	22	.974528	22	161	37 57-27/49
23	.404421	23	.990780	23	168	58 46-26/49
24	.467965	24	.998973	24	176	19 35-25/49
25	.532035	25	.998973	25	183	40 24-24/49
26	.595579	26	.990780	26	191	1 13-23/49
27	.657553	27	.974528	27	198	22 2-22/49
28	.716942	28	.950484	28	205	42 51-21/49
29	.772767	29	.919044	29	213	3 40-20/49
30	.824114	30	.880723	30	220	24 29-19/49
31	.870139	31	.836150	31	227	45 18-18/49
32	.910086	32	.786058	32	235	6 7-17/49
33	.943300	33	.731269	33	242	26 56-16/49
34	.969234	34	.672682	34	249	47 45-15/49
35	.987464	35	.611260	35	257	8 34-14/49
36	.997690	36	.548012	36	264	29 23-13/49
37	.999743	37	.483972	37	271	50 12-12/49
38	.993591	38	.420200	38	279	11 1-11/49
39	.979334	39	.357736	39	286	31 50-10/49
40	.957206	40	.297608	40	293	52 39- 9/49
41	.927571	41	.240804	41	301	13 28- 8/49
42	.890916	42	.188255	42	308	34 17- 7/49
43	.847841	43	.140825	43	315	55 6- 6/49
44	.799055	44	.099293	44	323	15 55- 5/49
45	.745359	45	.064341	45	330	36 44- 4/49
46	.687634	46	.036542	46	337	57 33- 3/49
47	.626825	47	.016353	47	345	18 22- 2/49
48	.563939	48	.004105	48	352	39 11- 1/49
49	.500000	49	.000000	49	360	0 0

50 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

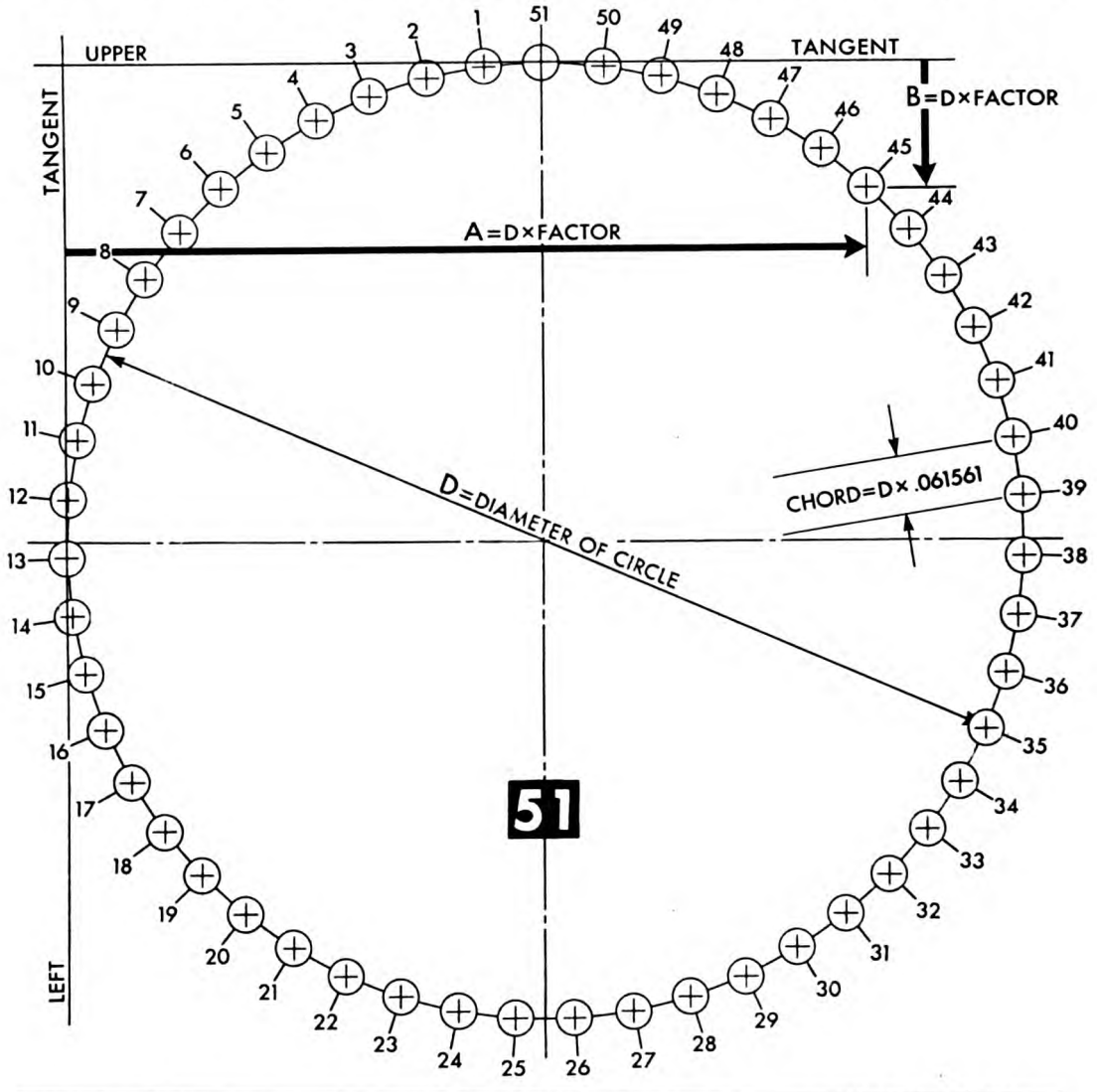


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.437333	1	.003943	1	7	12	0
2	.375655	2	.015708	2	14	24	0
3	.315937	3	.035112	3	21	36	0
4	.259123	4	.061847	4	28	48	0
5	.206107	5	.095492	5	36	00	0
6	.157726	6	.135516	6	43	12	0
7	.114743	7	.181288	7	50	24	0
8	.077836	8	.232087	8	57	36	0
9	.047586	9	.287110	9	64	48	0
10	.024472	10	.345492	10	72	00	0

COORDINATE FACTORS AND ANGLES—50 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
11	.008856	11	.406309	11	79	12	0
12	.000987	12	.468605	12	86	24	0
13	.000987	13	.531395	13	93	36	0
14	.008856	14	.593691	14	100	48	0
15	.024472	15	.654508	15	108	00	0
16	.047586	16	.712890	16	115	12	0
17	.077836	17	.767913	17	122	24	0
18	.114743	18	.818712	18	129	36	0
19	.157726	19	.864484	19	136	48	0
20	.206107	20	.904508	20	144	00	0
21	.259123	21	.938153	21	151	12	0
22	.315937	22	.964888	22	158	24	0
23	.375655	23	.984292	23	165	36	0
24	.437333	24	.996057	24	172	48	0
25	.500000	25	1.000000	25	180	00	0
26	.562667	26	.996057	26	187	12	0
27	.624345	27	.984292	27	194	24	0
28	.684062	28	.964888	28	201	36	0
29	.740877	29	.938153	29	208	48	0
30	.793893	30	.904508	30	216	00	0
31	.842274	31	.864484	31	223	12	0
32	.885257	32	.818712	32	230	24	0
33	.922164	33	.767913	33	237	36	0
34	.952414	34	.712890	34	244	48	0
35	.975528	35	.654508	35	252	00	0
36	.991144	36	.593691	36	259	12	0
37	.999013	37	.531395	37	266	24	0
38	.999013	38	.468605	38	273	36	0
39	.991144	39	.406309	39	280	48	0
40	.975528	40	.345492	40	288	00	0
41	.952414	41	.287110	41	295	12	0
42	.922164	42	.232087	42	302	24	0
43	.885257	43	.181288	43	309	36	0
44	.842274	44	.135516	44	316	48	0
45	.793893	45	.095492	45	324	00	0
46	.740877	46	.061847	46	331	12	0
47	.684062	47	.035112	47	338	24	0
48	.624345	48	.015708	48	345	36	0
49	.562667	49	.003943	49	352	48	0
50	.500000	50	.000000	50	360	0	0

51 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

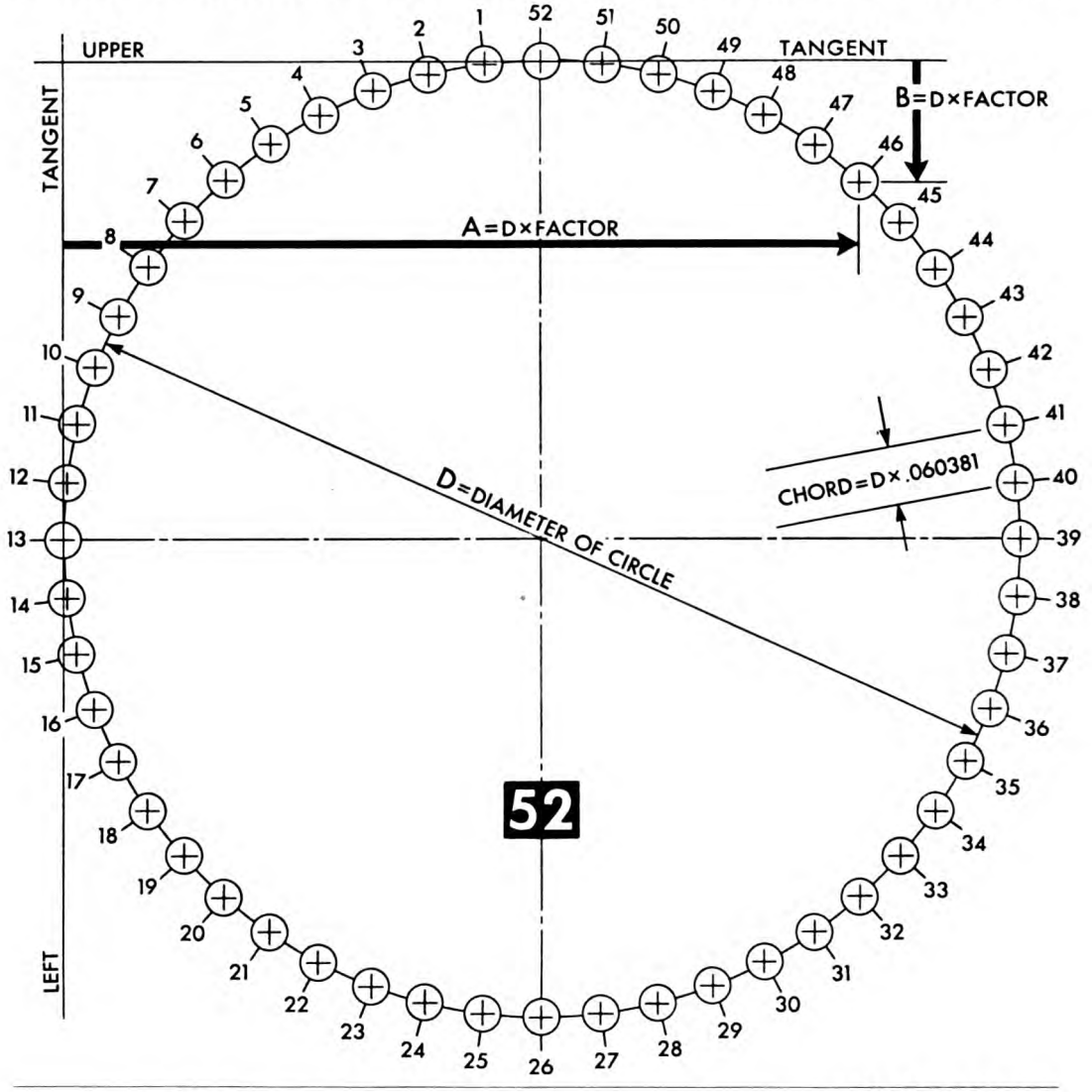


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.438556	1	.003790	1	7	3 31-39/51
2	.378043	2	.015102	2	14	7 3-27/51
3	.319379	3	.033764	3	21	10 35-15/51
4	.263453	4	.059494	4	28	14 7- 3/51
5	.211113	5	.091901	5	35	17 38-42/51
6	.163152	6	.130496	6	42	21 10-30/51
7	.120298	7	.174691	7	49	24 42-18/51
8	.083199	8	.223817	8	56	28 14- 6/51
9	.052418	9	.277131	9	63	31 45-45/51
10	.028423	10	.333823	10	70	35 17-33/51

COORDINATE FACTORS AND ANGLES—51 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
11	.011576	11	.393034	11	77	38 49–21/51
12	.002133	12	.453866	12	84	42 21– 9/51
13	.000237	13	.515398	13	91	45 52–48/51
14	.005917	14	.576696	14	98	49 24–36/51
15	.019087	15	.636832	15	105	52 56–24/51
16	.039547	16	.694893	16	112	56 28–12/51
17	.066987	17	.750000	17	120	00 00000000
18	.100991	18	.801317	18	127	3 31–39/51
19	.141044	19	.848067	19	134	7 3–27/51
20	.186538	20	.889540	20	141	10 35–15/51
21	.236784	21	.925109	21	148	14 7– 3/51
22	.291020	22	.954233	22	155	17 38–42/51
23	.348423	23	.976471	23	162	21 10–30/51
24	.408125	24	.991487	24	169	24 42–18/51
25	.469220	25	.999052	25	176	28 14– 6/51
26	.530780	26	.999052	26	183	31 45–45/51
27	.591875	27	.991487	27	190	35 17–33/51
28	.651577	28	.976471	28	197	38 49–21/51
29	.708980	29	.954233	29	204	42 21– 9/51
30	.763216	30	.925109	30	211	45 52–48/51
31	.813462	31	.889540	31	218	49 24–36/51
32	.858956	32	.848067	32	225	52 56–24/51
33	.899009	33	.801317	33	232	56 28–12/51
34	.933013	34	.750000	34	240	00 00000000
35	.960453	35	.694893	35	247	3 31–39/51
36	.980913	36	.636832	36	254	7 3–27/51
37	.994083	37	.576696	37	261	10 35–15/51
38	.999763	38	.515398	38	268	14 7– 3/51
39	.997867	39	.453866	39	275	17 38–42/51
40	.988424	40	.393034	40	282	21 10–30/51
41	.971577	41	.333823	41	289	24 42–18/51
42	.947582	42	.277131	42	296	28 14– 6/51
43	.916801	43	.223817	43	303	31 45–45/51
44	.879702	44	.174691	44	310	35 17–33/51
45	.836847	45	.130496	45	317	38 49–21/51
46	.788887	46	.091901	46	324	42 21– 9/51
47	.736547	47	.059494	47	331	45 52–48/51
48	.680621	48	.033764	48	338	49 24–36/51
49	.621957	49	.015102	49	345	52 56–24/51
50	.561444	50	.003790	50	352	56 28–12/51
51	.500000	51	.000000	51	360	0 0

52 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

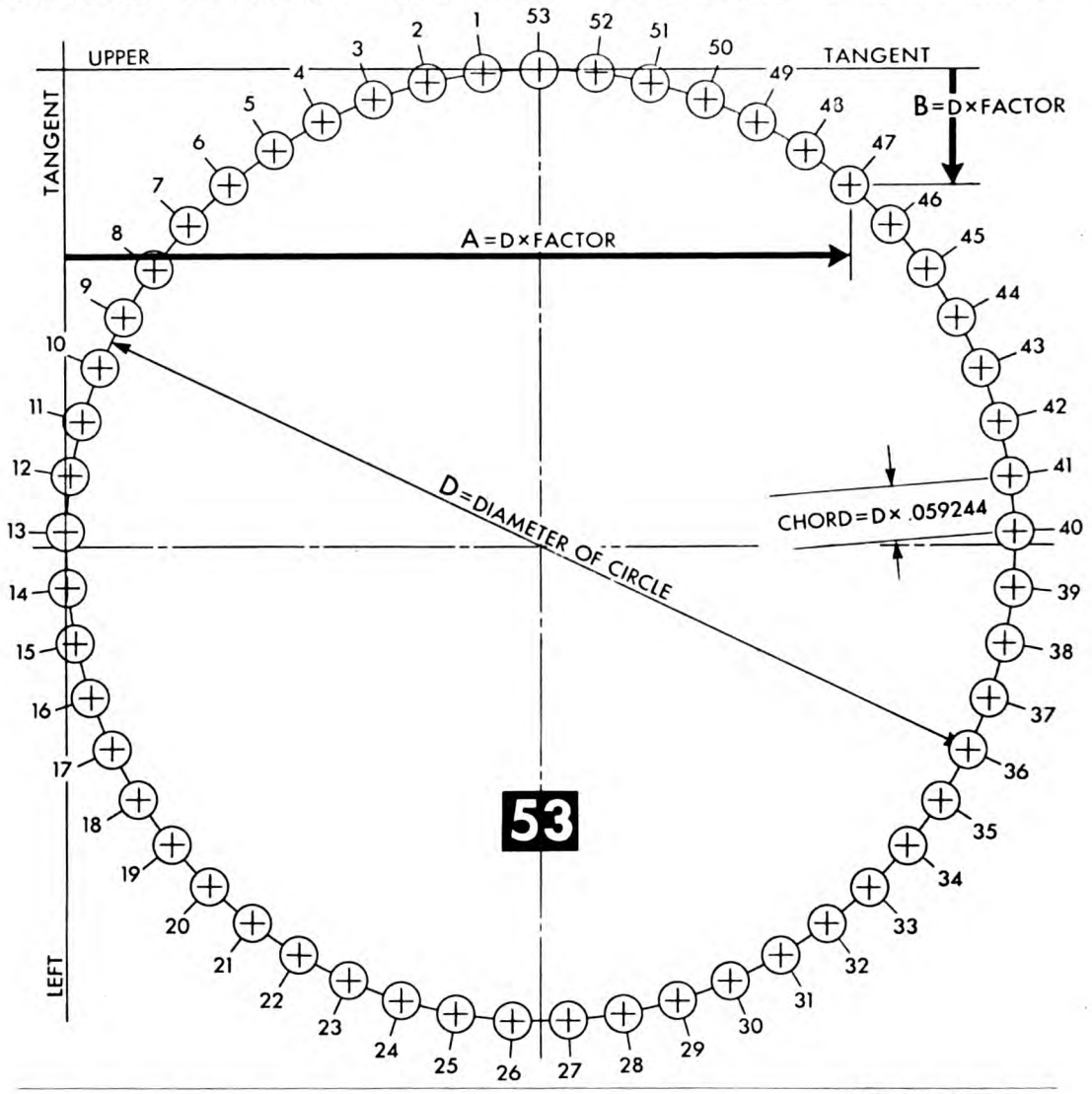


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.439732	1	.003646	1	6	55 23– 4/52
2	.380342	2	.014529	2	13	50 46– 8/52
3	.322698	3	.032492	3	20	46 9–12/52
4	.267638	4	.057272	4	27	41 32–16/52
5	.215968	5	.088508	5	34	36 55–20/52
6	.168439	6	.125745	6	41	32 18–24/52
7	.125745	7	.168439	7	48	27 41–28/52
8	.088508	8	.215968	8	55	23 4–32/52
9	.057272	9	.267638	9	62	18 27–36/52
10	.032492	10	.322698	10	69	13 50–40/52
11	.014529	11	.380342	11	76	9 13–44/52

COORDINATE FACTORS AND ANGLES—52 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
12	.003646	12	.439732	12	83	4 36–48/52
13	.000000	13	.500000	13	90	00 00000000
14	.003646	14	.560268	14	96	55 23– 4/52
15	.014529	15	.619658	15	103	50 46– 8/52
16	.032492	16	.677302	16	110	46 9–12/52
17	.057272	17	.732362	17	117	41 32–16/52
18	.088508	18	.784032	18	124	36 55–20/52
19	.125745	19	.831561	19	131	32 18–24/52
20	.168439	20	.874255	20	138	27 41–28/52
21	.215968	21	.911492	21	145	23 4–32/52
22	.267638	22	.942728	22	152	18 27–36/52
23	.322698	23	.967508	23	159	13 50–40/52
24	.380342	24	.985471	24	166	9 13–44/52
25	.439732	25	.996354	25	173	4 36–48/52
26	.500000	26	1.000000	26	180	00 00000000
27	.560268	27	.996354	27	186	55 23– 4/52
28	.619658	28	.985471	28	193	50 46– 8/52
29	.677302	29	.967508	29	200	46 9–12/52
30	.732362	30	.942728	30	207	41 32–16/52
31	.784032	31	.911492	31	214	36 55–20/52
32	.831561	32	.874255	32	221	32 18–24/52
33	.874255	33	.831561	33	228	27 41–28/52
34	.911492	34	.784032	34	235	23 4–32/52
35	.942728	35	.732362	35	242	18 27–36/52
36	.967508	36	.677302	36	249	13 50–40/52
37	.985471	37	.619658	37	256	9 13–44/52
38	.996354	38	.560268	38	263	4 36–48/52
39	1.000000	39	.500000	39	270	00 00000000
40	.996354	40	.439732	40	276	55 23– 4/52
41	.985471	41	.380342	41	283	50 46– 8/52
42	.967508	42	.322698	42	290	46 9–12/52
43	.942728	43	.267638	43	297	41 32–16/52
44	.911492	44	.215968	44	304	36 55–20/52
45	.874255	45	.168439	45	311	32 18–24/52
46	.831561	46	.125745	46	318	27 41–28/52
47	.784032	47	.088508	47	325	23 4–32/52
48	.732362	48	.057272	48	332	18 27–36/52
49	.677302	49	.032492	49	339	13 50–40/52
50	.619658	50	.014529	50	346	9 13–44/52
51	.560268	51	.003646	51	353	4 36–48/52
52	.500000	52	.000000	52	360	0 0

53 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

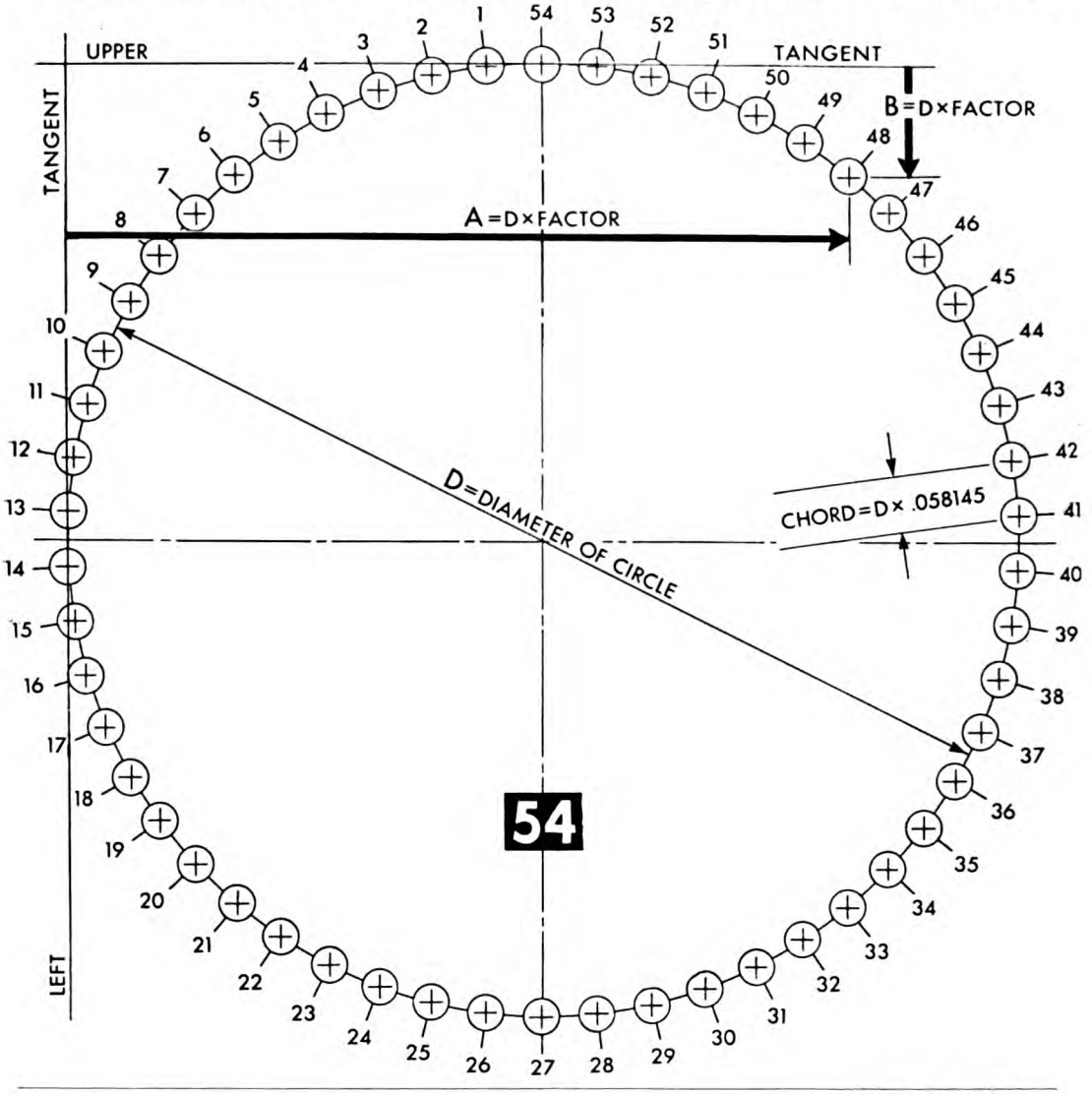


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.440863	1	.003510	1	6	47	32–44/53
2	.382557	2	.013989	2	13	35	5–35/53
3	.325899	3	.031290	3	20	22	38–26/53
4	.271685	4	.055172	4	27	10	11–17/53
5	.220677	5	.085299	5	33	57	44– 8/53
6	.173590	6	.121244	6	40	45	16–52/53
7	.131083	7	.162509	7	47	32	49–43/53
8	.093757	8	.208510	8	54	20	22–34/53
9	.062133	9	.258603	9	61	7	55–25/53
10	.036655	10	.312086	10	67	55	28–16/53
11	.017682	11	.368206	11	74	43	1– 7/53

COORDINATE FACTORS AND ANGLES—53 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.005480	12	.426177	12	81	30 33–51/53
13	.000220	13	.485183	13	68	18 6–42/53
14	.001975	14	.544398	14	95	5 39–33/53
15	.010722	15	.602990	15	101	53 12–24/53
16	.026337	16	.660135	16	108	40 45–15/53
17	.048601	17	.715033	17	115	28 18– 6/53
18	.077202	18	.766912	18	122	15 50–50/53
19	.111738	19	.815044	19	129	3 23–41/53
20	.151725	20	.858754	20	135	50 56–32/53
21	.196600	21	.897427	21	142	38 29–23/53
22	.245734	22	.930522	22	149	26 2–14/53
23	.298438	23	.957573	23	156	13 35– 5/53
24	.353972	24	.978201	24	163	1 7–49/53
25	.411555	25	.992115	25	169	48 40–40/53
26	.470380	26	.999122	26	176	36 13–31/53
27	.529620	27	.999122	27	183	23 46–22/53
28	.588445	28	.992115	28	190	11 19–13/53
29	.646028	29	.978201	29	196	58 52– 4/53
30	.701562	30	.957573	30	203	46 24–48/53
31	.754266	31	.930522	31	210	33 57–39/53
32	.803400	32	.897427	32	217	21 30–30/53
33	.848276	33	.858754	33	224	9 3–21/53
34	.888262	34	.815044	34	230	56 36–12/53
35	.922798	35	.766912	35	237	44 9– 3/53
36	.951399	36	.715033	36	244	31 41–47/53
37	.973663	37	.660135	37	251	19 14–38/53
38	.989278	38	.602990	38	258	6 47–29/53
39	.998025	39	.544398	39	264	54 20–20/53
40	.999780	40	.485183	40	271	41 53–11/53
41	.994520	41	.426177	41	278	29 26– 2/53
42	.982318	42	.368206	42	285	16 58–46/53
43	.963345	43	.312086	43	292	4 31–37/53
44	.937868	44	.258603	44	298	52 4–28/53
45	.906243	45	.208510	45	305	39 37–19/53
46	.868917	46	.162509	46	312	27 10–10/53
47	.826410	47	.121244	47	319	14 43– 1/53
48	.779323	48	.085299	48	326	2 15–45/53
49	.728315	49	.055172	49	332	49 48–36/53
50	.674101	50	.031290	50	339	37 21–27/53
51	.617443	51	.013989	51	346	24 54–18/53
52	.559137	52	.003510	52	353	12 27– 9/53
53	.500000	53	.000000	53	360	0 0

54 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

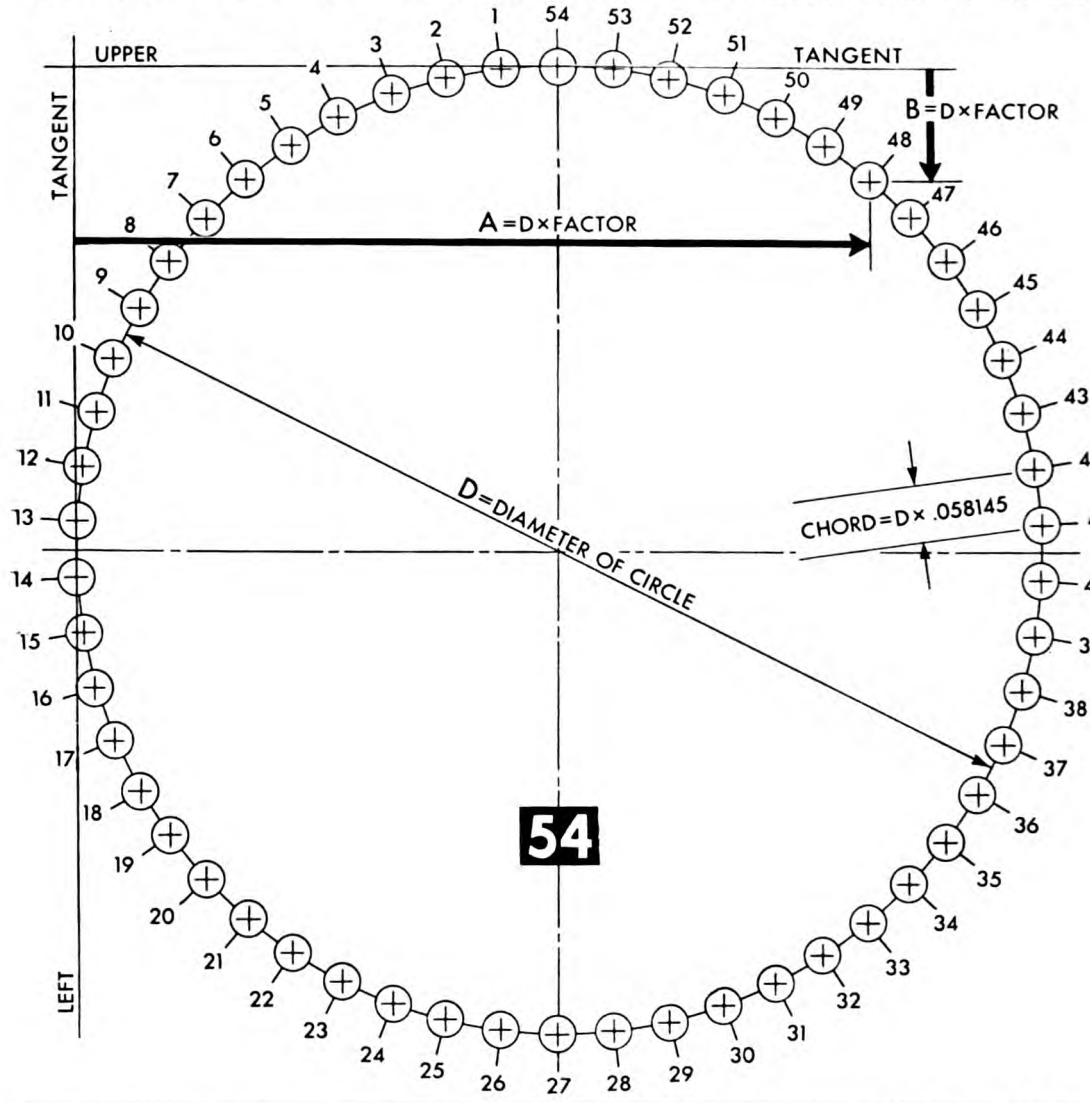


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.441954	1	.003381	1	6	40	0
2	.384692	2	.013478	1	13	20	0
3	.328990	3	.030154	3	20	00	0
4	.275600	4	.053184	4	26	40	0
5	.225246	5	.082256	5	33	20	0
6	.178606	6	.116978	6	40	00	0
7	.136313	7	.156879	7	46	40	0
8	.098938	8	.201421	8	53	20	0
9	.066987	9	.250000	9	60	00	0
10	.040892	10	.301960	10	66	40	0
11	.021005	11	.356598	11	73	20	0

COORDINATE FACTORS AND ANGLES—54 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
12	.007596	12	.413176	12	80	00	0
13	.000846	13	.470928	13	86	40	0
14	.000846	14	.529072	14	93	20	0
15	.007596	15	.586824	15	100	00	0
16	.021005	16	.643402	16	106	40	0
17	.040892	17	.698040	17	113	20	0
18	.066987	18	.750000	18	120	00	0
19	.098938	19	.798579	19	126	40	0
20	.136313	20	.843121	20	133	20	0
21	.178606	21	.883022	21	140	00	0
22	.225246	22	.917744	22	146	40	0
23	.275600	23	.946816	23	153	20	0
24	.328990	24	.969846	24	160	00	0
25	.384692	25	.986522	25	166	40	0
26	.441954	26	.996619	26	173	20	0
27	.500000	27	1.000000	27	180	00	0
28	.558046	28	.996619	28	186	40	0
29	.615308	29	.986522	29	193	20	0
30	.671010	30	.969846	30	200	00	0
31	.724400	31	.946816	31	206	40	0
32	.774755	32	.917744	32	213	20	0
33	.821394	33	.883022	33	220	00	0
34	.863687	34	.843121	34	226	40	0
35	.901062	35	.798579	35	233	20	0
36	.933013	36	.750000	36	240	00	0
37	.959108	37	.698040	37	246	40	0
38	.978995	38	.643402	38	253	20	0
39	.992404	39	.586824	39	260	00	0
40	.999154	40	.529072	40	266	40	0
41	.999154	41	.470928	41	273	20	0
42	.992404	42	.413176	42	280	00	0
43	.978995	43	.356598	43	286	40	0
44	.959108	44	.301960	44	293	20	0
45	.933013	45	.250000	45	300	00	0
46	.901062	46	.201421	46	306	40	0
47	.863687	47	.156879	47	313	20	0
48	.821394	48	.116978	48	320	00	0
49	.774755	49	.082256	49	326	40	0
50	.724400	50	.053184	50	333	20	0
51	.671010	51	.030154	51	340	00	0
52	.615308	52	.013478	52	346	40	0
53	.558046	53	.003381	53	353	20	0
54	.500000	54	.000000	54	360	0	0

54 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

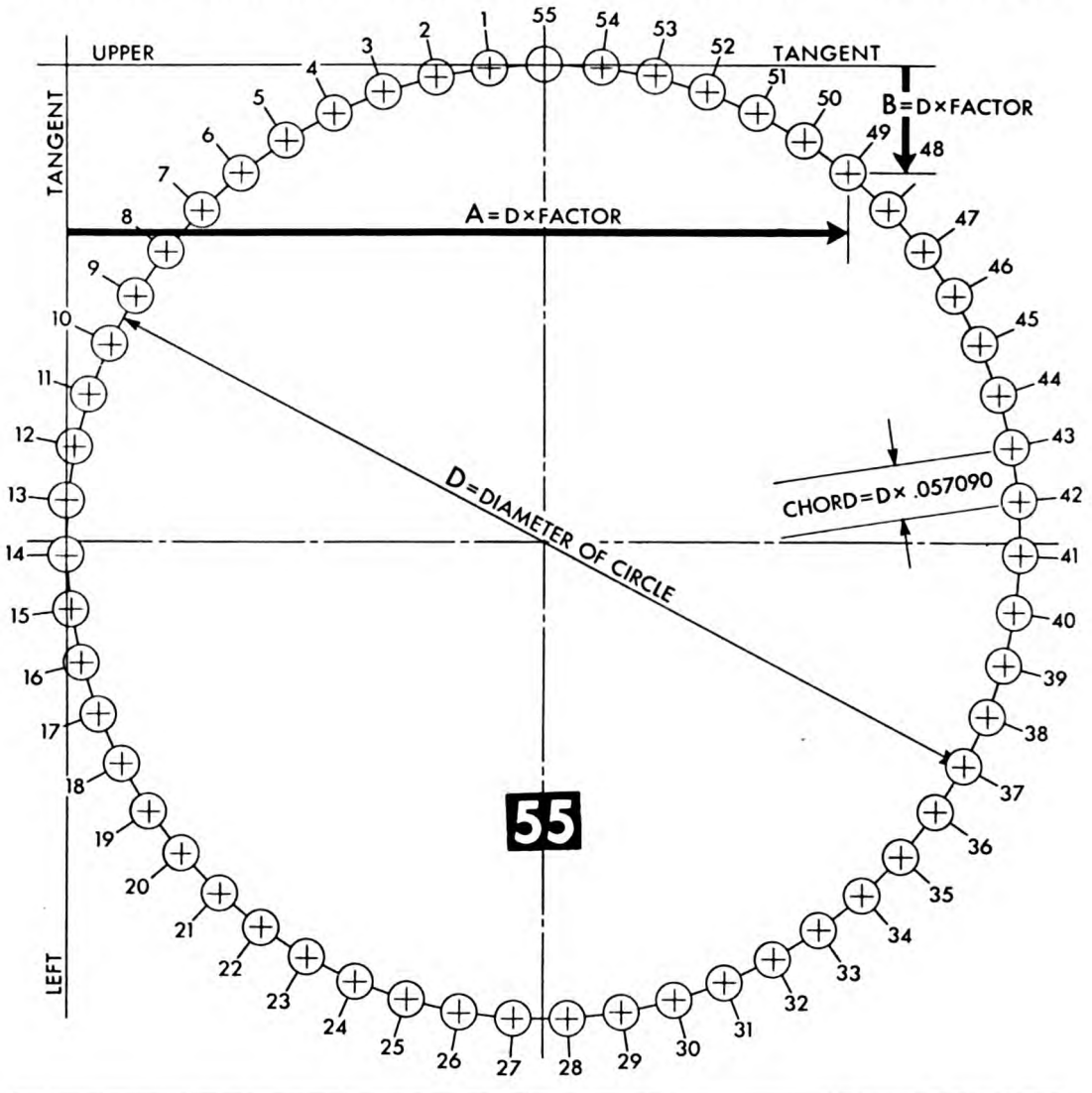


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.441954	1	.003381	1	6	40	0
2	.384692	2	.013478	1	13	20	0
3	.328990	3	.030154	3	20	00	0
4	.275600	4	.053184	4	26	40	0
5	.225246	5	.082256	5	33	20	0
6	.178606	6	.116978	6	40	00	0
7	.136313	7	.156879	7	46	40	0
8	.098938	8	.201421	8	53	20	0
9	.066987	9	.250000	9	60	00	0
10	.040892	10	.301960	10	66	40	0
11	.021005	11	.356598	11	73	20	0

COORDINATE FACTORS AND ANGLES—54 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.007596	12	.413176	12	80	00	0
13	.000846	13	.470928	13	86	40	0
14	.000846	14	.529072	14	93	20	0
15	.007596	15	.586824	15	100	00	0
16	.021005	16	.643402	16	106	40	0
17	.040892	17	.698040	17	113	20	0
18	.066987	18	.750000	18	120	00	0
19	.098938	19	.798579	19	126	40	0
20	.136313	20	.843121	20	133	20	0
21	.178606	21	.883022	21	140	00	0
22	.225246	22	.917744	22	146	40	0
23	.275600	23	.946816	23	153	20	0
24	.328990	24	.969846	24	160	00	0
25	.384692	25	.986522	25	166	40	0
26	.441954	26	.996619	26	173	20	0
27	.500000	27	1.000000	27	180	00	0
28	.558046	28	.996619	28	186	40	0
29	.615308	29	.986522	29	193	20	0
30	.671010	30	.969846	30	200	00	0
31	.724400	31	.946816	31	206	40	0
32	.774755	32	.917744	32	213	20	0
33	.821394	33	.883022	33	220	00	0
34	.863687	34	.843121	34	226	40	0
35	.901062	35	.798579	35	233	20	0
36	.933013	36	.750000	36	240	00	0
37	.959108	37	.698040	37	246	40	0
38	.978995	38	.643402	38	253	20	0
39	.992404	39	.586824	39	260	00	0
40	.999154	40	.529072	40	266	40	0
41	.999154	41	.470928	41	273	20	0
42	.992404	42	.413176	42	280	00	0
43	.978995	43	.356598	43	286	40	0
44	.959108	44	.301960	44	293	20	0
45	.933013	45	.250000	45	300	00	0
46	.901062	46	.201421	46	306	40	0
47	.863687	47	.156879	47	313	20	0
48	.821394	48	.116978	48	320	00	0
49	.774755	49	.082256	49	326	40	0
50	.724400	50	.053184	50	333	20	0
51	.671010	51	.030154	51	340	00	0
52	.615308	52	.013478	52	346	40	0
53	.558046	53	.003381	53	353	20	0
54	.500000	54	.000000	54	360	0	0

55 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

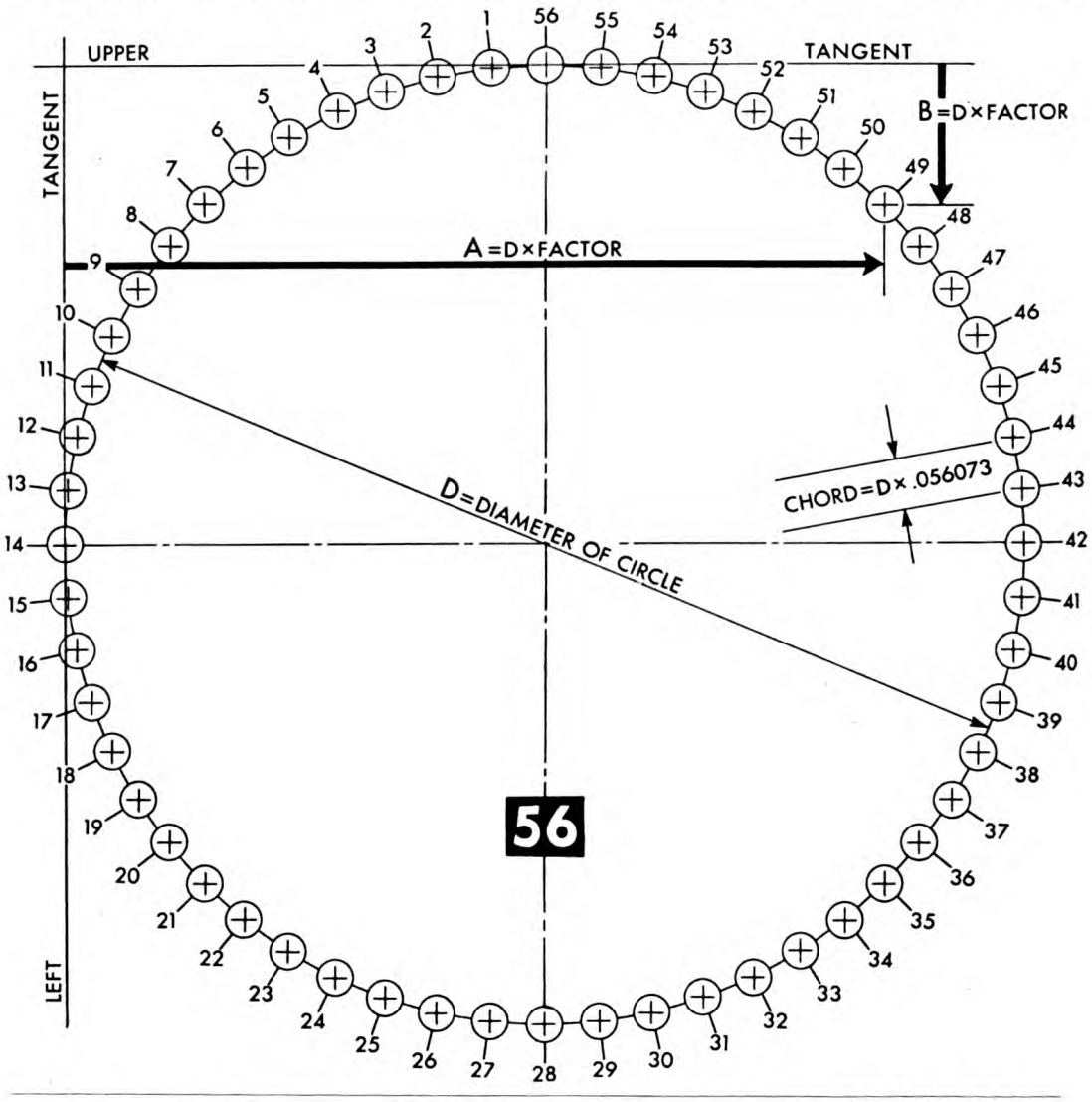


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.443004	1	.003259	1	6	32	43-35/55
2	.386752	2	.012994	2	13	5	27-15/55
3	.331975	3	.029078	3	19	38	10-50/55
4	.279389	4	.051301	4	26	10	54-30/55
5	.229680	5	.079373	5	32	43	38-10/55
6	.183494	6	.112929	6	39	16	21-45/55
7	.141434	7	.151531	7	45	49	5-25/55
8	.104049	8	.194678	8	52	21	49- 5/55
9	.071826	9	.241801	9	58	54	32-40/55
10	.045184	10	.292293	10	65	27	16-20/55
11	.024472	11	.345492	11	72	00	00000000

COORDINATE FACTORS AND ANGLES—55 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
12	.009957	12	.400705	12	78	32	43–35/55
13	.001834	13	.457213	13	85	5	27–15/55
14	.000204	14	.514278	14	91	38	10–50/55
15	.005089	15	.571157	15	98	10	54–30/55
16	.016427	16	.627109	16	104	43	38–10/55
17	.034068	17	.681404	17	111	16	21–45/55
18	.057784	18	.733334	18	117	49	5–25/55
19	.087264	19	.782222	19	124	21	49– 5/55
20	.122125	20	.827430	20	130	54	32–40/55
21	.161913	21	.868371	21	137	27	16–20/55
22	.206107	22	.904509	22	144	00	00000000
23	.254134	23	.935373	23	150	32	43–35/55
24	.305365	24	.960562	24	157	5	27–15/55
25	.359134	25	.979747	25	163	38	10–50/55
26	.414739	26	.992677	26	170	10	54–30/55
27	.471456	27	.999185	27	176	43	38–10/55
28	.528544	28	.999185	28	183	16	21–45/55
29	.585261	29	.992677	29	189	49	5–25/55
30	.640866	30	.979747	30	196	21	49– 5/55
31	.694635	31	.960562	31	202	54	32–40/55
32	.745867	32	.935373	32	209	27	16–20/55
33	.793893	33	.904509	33	216	00	00000000
34	.838087	34	.868371	34	222	32	43–35/55
35	.877875	35	.827430	35	229	5	27–15/55
36	.912736	36	.782222	36	235	38	10–50/55
37	.942217	37	.733334	37	242	10	54–30/55
38	.965932	38	.681404	38	248	43	38–10/55
39	.983573	39	.627109	39	255	16	21–45/55
40	.994911	40	.571157	40	261	49	5–25/55
41	.999796	41	.514278	41	268	21	49– 5/55
42	.998166	42	.457213	42	274	54	32–40/55
43	.990041	43	.400705	43	281	27	16–20/55
44	.975528	44	.345492	44	288	00	00000000
45	.954816	45	.292293	45	294	32	43–35/55
46	.928175	46	.241801	46	301	5	27–15/55
47	.895951	47	.194678	47	307	38	10–50/55
48	.858566	48	.151531	48	314	10	54–30/55
49	.816506	49	.112929	49	320	43	38–10/55
50	.770321	50	.079373	50	327	16	21–45/55
51	.720611	51	.051301	51	333	49	5–25/55
52	.668025	52	.029078	52	340	21	49– 5/55
53	.613249	53	.012994	53	346	54	32–40/55
54	.556996	54	.003259	54	353	27	16–20/55
55	.500000	55	.000000	55	360	0	0

56 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

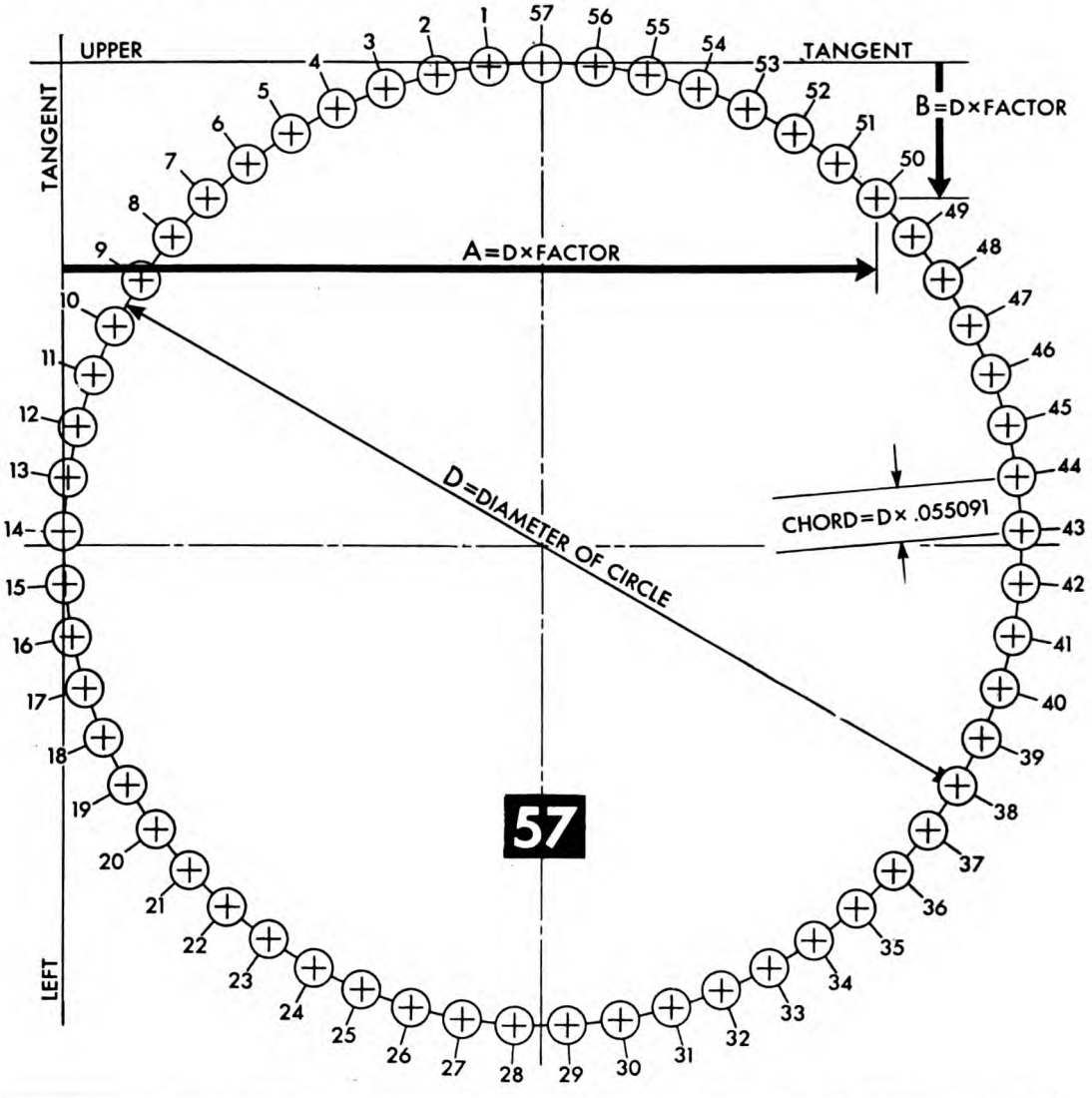


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.444018	1	.003144	1	6	25 42–48/56
2	.388740	2	.012536	2	12	51 25–40/56
3	.334861	3	.028058	3	19	17 8–32/56
4	.283058	4	.049516	4	25	42 51–24/56
5	.233984	5	.076638	5	32	8 34–16/56
6	.188255	6	.109084	6	38	34 17– 8/56
7	.146447	7	.146447	7	45	00 00000000
8	.109084	8	.188255	8	51	25 42–48/56
9	.076638	9	.233984	9	57	51 25–40/56
10	.049516	10	.283058	10	64	17 8–32/56
11	.028058	11	.334861	11	70	42 51–24/56

COORDINATE FACTORS AND ANGLES—56 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
12	.012536	12	.388740	12	77	8	34-16/56
13	.003144	13	.444018	13	83	34	17- 8/56
14	.000000	14	.500000	14	90	00	00000000
15	.003144	15	.555982	15	96	25	42-48/56
16	.012536	16	.611261	16	102	51	25-40/56
17	.028058	17	.665140	17	109	17	8-32/56
18	.049516	18	.716942	18	115	42	51-24/56
19	.076638	19	.766016	19	122	8	34-16/56
20	.109084	20	.811745	20	128	34	17- 8/56
21	.146447	21	.853553	21	135	00	00000000
22	.188255	22	.890916	22	141	25	42-48/56
23	.233984	23	.923362	23	147	51	25-40/56
24	.283058	24	.950484	24	154	17	8-32/56
25	.334861	25	.971942	25	160	42	51-24/56
26	.388740	26	.987464	26	167	8	34-16/56
27	.444018	27	.996856	27	173	34	17- 8/56
28	.500000	28	1.000000	28	180	00	00000000
29	.555982	29	.996856	29	186	25	42-48/56
30	.611261	30	.987464	30	192	51	25-40/56
31	.665140	31	.971942	31	199	17	8-32/56
32	.716942	32	.950484	32	205	42	51-24/56
33	.766016	33	.923362	33	212	8	34-16/56
34	.811745	34	.890916	34	218	34	17- 8/56
35	.853553	35	.853553	35	225	00	00000000
36	.890916	36	.811745	36	231	25	42-48/56
37	.923362	37	.766016	37	237	51	25-40/56
38	.950484	38	.716942	38	244	17	8-32/56
39	.971942	39	.665140	39	250	42	51-24/56
40	.987464	40	.611261	40	257	8	34-16/56
41	.996856	41	.555982	41	263	34	17- 8/56
42	1.000000	42	.500000	42	270	00	00000000
43	.996856	43	.444018	43	276	25	42-48/56
44	.987464	44	.388740	44	282	51	25-40/56
45	.971942	45	.334861	45	289	17	8-32/56
46	.950484	46	.283058	46	295	42	51-24/56
47	.923362	47	.233984	47	302	8	34-16/56
48	.890916	48	.188255	48	308	34	17- 8/56
49	.853553	49	.146447	49	315	00	00000000
50	.811745	50	.109084	50	321	25	42-48/56
51	.766016	51	.076638	51	327	51	25-40/56
52	.716942	52	.049516	52	334	17	8-32/56
53	.665140	53	.028058	53	340	42	51-24/56
54	.611261	54	.012536	54	347	8	34-16/56
55	.555982	55	.003144	55	353	34	17- 8/56
56	.500000	56	.000000	56	360	0	0

57 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

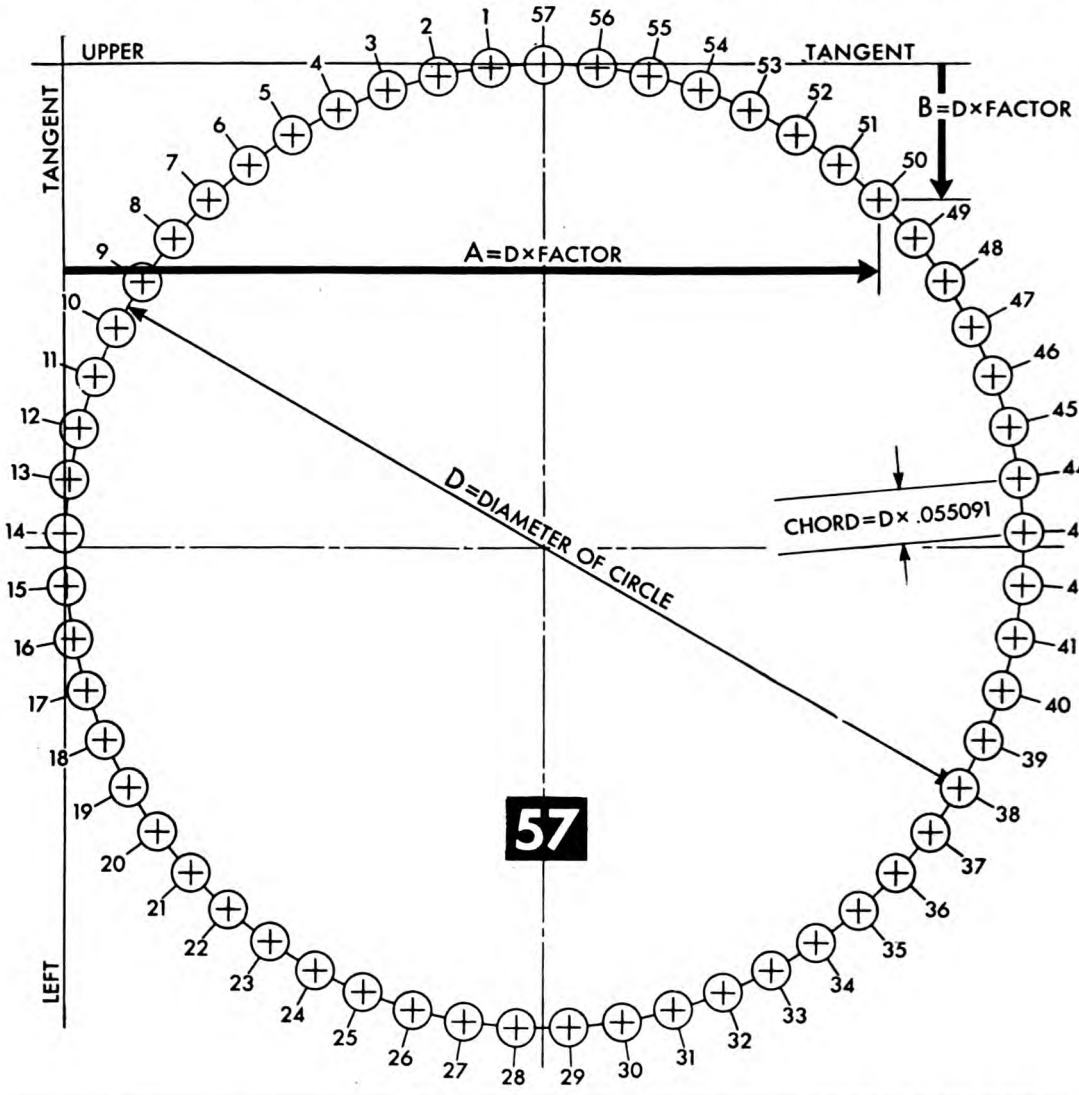


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.444996	1	.003035	1	6	18	56-48/57
2	.390660	2	.012102	2	12	37	53-39/57
3	.337650	3	.027091	3	18	56	50-30/57
4	.286612	4	.047822	4	25	15	47-21/57
5	.238164	5	.074040	5	31	34	44-12/57
6	.192894	6	.105430	6	37	53	41- 3/57
7	.151352	7	.141609	7	44	12	37-51/57
8	.114042	8	.182138	8	50	31	34-42/57
9	.081417	9	.226526	9	56	50	31-33/57
10	.053873	10	.274233	10	63	9	28-24/57
11	.031744	11	.324681	11	69	28	25-15/57

COORDINATE FACTORS AND ANGLES—56 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
12	.012536	12	.388740	12	77	8	34–16/56
13	.003144	13	.444018	13	83	34	17– 8/56
14	.000000	14	.500000	14	90	00	00000000
15	.003144	15	.555982	15	96	25	42–48/56
16	.012536	16	.611261	16	102	51	25–40/56
17	.028058	17	.665140	17	109	17	8–32/56
18	.049516	18	.716942	18	115	42	51–24/56
19	.076638	19	.766016	19	122	8	34–16/56
20	.109084	20	.811745	20	128	34	17– 8/56
21	.146447	21	.853553	21	135	00	00000000
22	.188255	22	.890916	22	141	25	42–48/56
23	.233984	23	.923362	23	147	51	25–40/56
24	.283058	24	.950484	24	154	17	8–32/56
25	.334861	25	.971942	25	160	42	51–24/56
26	.388740	26	.987464	26	167	8	34–16/56
27	.444018	27	.996856	27	173	34	17– 8/56
28	.500000	28	1.000000	28	180	00	00000000
29	.555982	29	.996856	29	186	25	42–48/56
30	.611261	30	.987464	30	192	51	25–40/56
31	.665140	31	.971942	31	199	17	8–32/56
32	.716942	32	.950484	32	205	42	51–24/56
33	.766016	33	.923362	33	212	8	34–16/56
34	.811745	34	.890916	34	218	34	17– 8/56
35	.853553	35	.853553	35	225	00	00000000
36	.890916	36	.811745	36	231	25	42–48/56
37	.923362	37	.766016	37	237	51	25–40/56
38	.950484	38	.716942	38	244	17	8–32/56
39	.971942	39	.665140	39	250	42	51–24/56
40	.987464	40	.611261	40	257	8	34–16/56
41	.996856	41	.555982	41	263	34	17– 8/56
42	1.000000	42	.500000	42	270	00	00000000
43	.996856	43	.444018	43	276	25	42–48/56
44	.987464	44	.388740	44	282	51	25–40/56
45	.971942	45	.334861	45	289	17	8–32/56
46	.950484	46	.283058	46	295	42	51–24/56
47	.923362	47	.233984	47	302	8	34–16/56
48	.890916	48	.188255	48	308	34	17– 8/56
49	.853553	49	.146447	49	315	00	00000000
50	.811745	50	.109084	50	321	25	42–48/56
51	.766016	51	.076638	51	327	51	25–40/56
52	.716942	52	.049516	52	334	17	8–32/56
53	.665140	53	.028058	53	340	42	51–24/56
54	.611261	54	.012536	54	347	8	34–16/56
55	.555982	55	.003144	55	353	34	17– 8/56
56	.500000	56	.000000	56	360	0	0

57 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

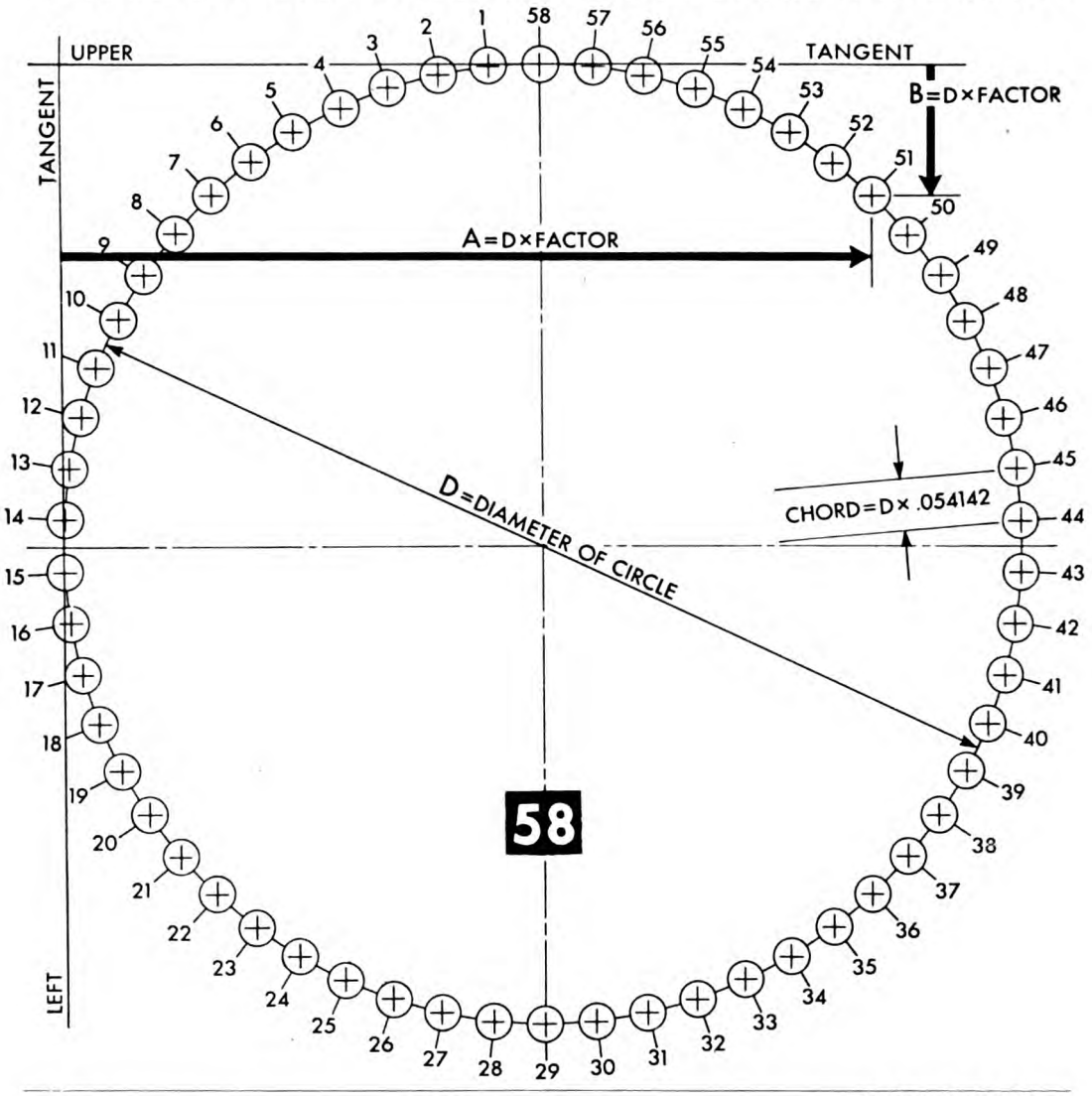


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.444996	1	.003035	1	6	18	56–48/57
2	.390660	2	.012102	2	12	37	53–39/57
3	.337650	3	.027091	3	18	56	50–30/57
4	.286612	4	.047822	4	25	15	47–21/57
5	.238164	5	.074040	5	31	34	44–12/57
6	.192894	6	.105430	6	37	53	41– 3/57
7	.151352	7	.141609	7	44	12	37–51/57
8	.114042	8	.182138	8	50	31	34–42/57
9	.081417	9	.226526	9	56	50	31–33/57
10	.053873	10	.274233	10	63	9	28–24/57
11	.031744	11	.324681	11	69	28	25–15/57

COORDINATE FACTORS AND ANGLES—57 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
12	.015300	12	.377257	12	75	47	22- 6/57
13	.004739	13	.431323	13	82	6	18-54/57
14	.000190	14	.486223	14	88	25	15-45/57
15	.001708	15	.541290	15	94	44	12-36/57
16	.009274	16	.595855	16	101	3	9-27/57
17	.022798	17	.649257	17	107	22	6-18/57
18	.042113	18	.700848	18	113	41	3- 9/57
19	.066987	19	.750000	19	120	00	00000000
20	.097118	20	.796118	20	126	18	56-48/57
21	.132138	21	.838641	21	132	37	53-39/57
22	.171624	22	.877054	22	138	56	50-30/57
23	.215096	23	.910889	23	145	15	47-21/57
24	.262026	24	.939737	24	151	34	44-12/57
25	.311845	25	.963247	25	157	53	41- 3/57
26	.363948	26	.981134	26	164	12	37-51/57
27	.417703	27	.993181	27	170	31	34-42/57
28	.472456	28	.999241	28	176	50	31-33/57
29	.527544	29	.999241	29	183	9	28-24/57
30	.582297	30	.993181	30	189	28	25-15/57
31	.636052	31	.981134	31	195	47	22- 6/57
32	.688155	32	.963247	32	202	6	18-54/57
33	.737974	33	.939737	33	208	25	15-45/57
34	.784904	34	.910889	34	214	44	12-36/57
35	.828376	35	.877054	35	221	3	9-27/57
36	.867862	36	.838641	36	227	22	6-18/57
37	.902883	37	.796118	37	233	41	3- 9/57
38	.933013	38	.750000	38	240	00	00000000
39	.957887	39	.700848	39	246	18	56-48/57
40	.977203	40	.649257	40	252	37	53-39/57
41	.990726	41	.595855	41	258	56	50-30/57
42	.998292	42	.541290	42	265	15	47-21/57
43	.999810	43	.486223	43	271	34	44-12/57
44	.995261	44	.431323	44	277	53	41- 3/57
45	.984700	45	.377257	45	284	12	37-51/57
46	.968256	46	.324681	46	290	31	34-42/57
47	.946127	47	.274233	47	296	50	31-33/57
48	.918583	48	.226526	48	303	9	28-24/57
49	.885958	49	.182138	49	309	28	25-15/57
50	.848648	50	.141609	50	315	47	22- 6/57
51	.807106	51	.105430	51	322	6	18-54/57
52	.761837	52	.074040	52	328	25	15-45/57
53	.713388	53	.047822	53	334	44	12-36/57
54	.662350	54	.027091	54	341	3	9-27/57
55	.609340	55	.012102	55	347	22	6-18/57
56	.555004	56	.003035	56	353	41	3- 9/57
57	.500000	57	.000000	57	360	0	0

58 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

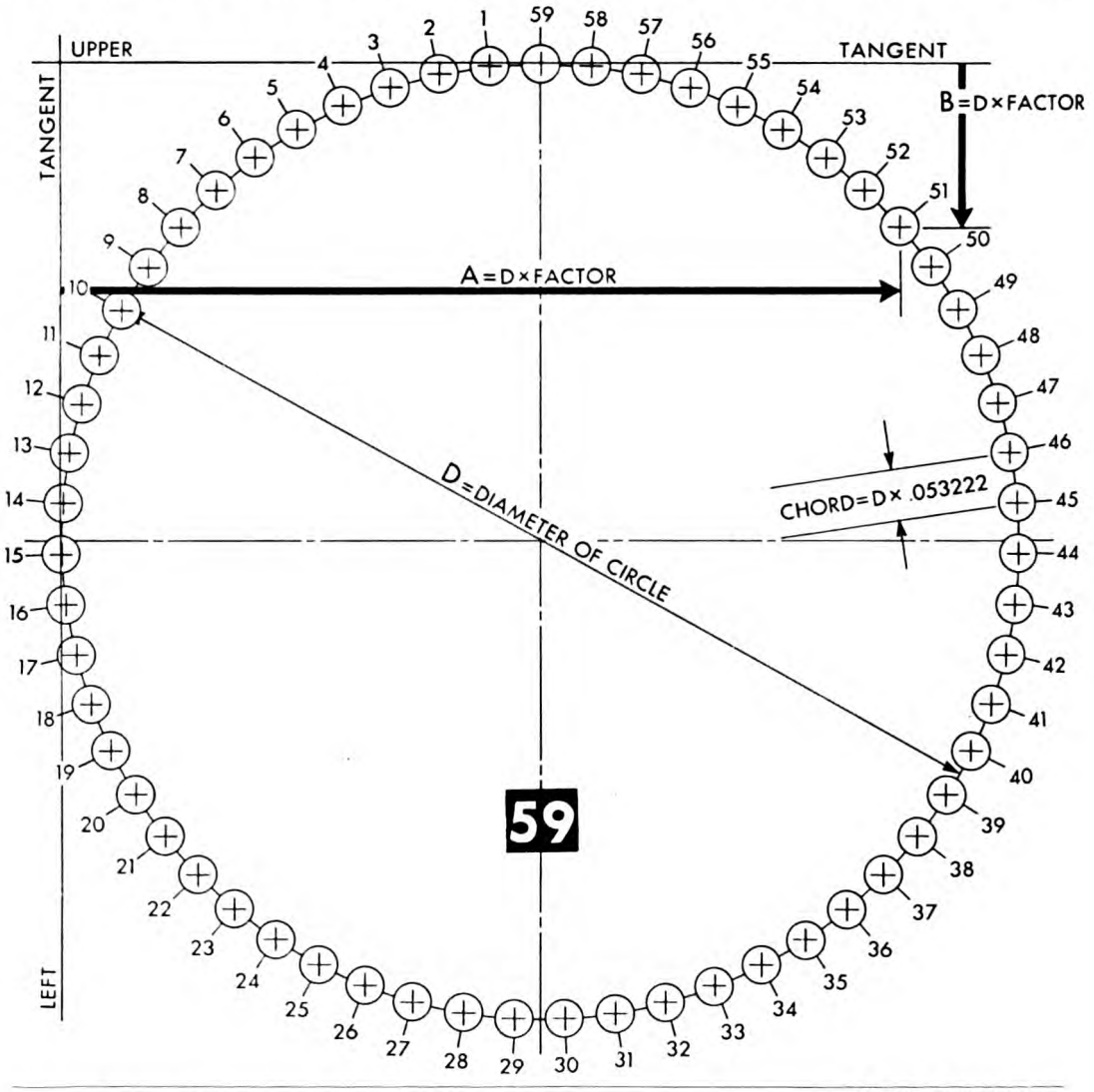


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.445941	1	.002931	1	6	12 24-48/58
2	.392515	2	.011689	2	12	24 49-38/58
3	.340349	3	.026173	3	18	37 14-28/58
4	.290056	4	.046212	4	24	49 39-18/58
5	.242223	5	.071571	5	31	2 4- 8/58
6	.197413	6	.101954	6	37	14 28-56/58
7	.156150	7	.137002	7	43	26 53-46/58
8	.118919	8	.176305	8	49	39 18-36/58
9	.086155	9	.219407	9	55	51 43-26/58
10	.058244	10	.265796	10	62	4 8-16/58
11	.035511	11	.314931	11	68	16 33- 6/58
12	.018225	12	.366236	12	74	28 57-54/58

COORDINATE FACTORS AND ANGLES—58 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
13	.006587	13	.419109	13	80	41	22-44/58
14	.000733	14	.472931	14	86	53	47-34/58
15	.000733	15	.527070	15	93	6	12-24/58
16	.006587	16	.580891	16	99	18	37-14/58
17	.018225	17	.633764	17	105	31	2- 4/58
18	.035512	18	.685069	18	111	43	26-52/58
19	.058244	19	.734204	19	117	55	51-42/58
20	.086155	20	.780594	20	124	8	16-32/58
21	.118919	21	.823695	21	130	20	41-22/58
22	.156150	22	.862998	22	136	33	6-12/58
23	.197413	23	.898047	23	142	45	31- 2/58
24	.242223	24	.928429	24	148	57	55-50/58
25	.290056	25	.953788	25	155	10	20-40/58
26	.340349	26	.973827	26	161	22	45-30/58
27	.392515	27	.988311	27	167	35	10-20/58
28	.445941	28	.997069	28	173	47	35-10/58
29	.500000	29	1.000000	29	180	00	00000000
30	.554060	30	.997069	30	186	12	24-48/58
31	.607485	31	.988311	31	192	24	49-38/58
32	.659651	32	.973827	32	198	37	14-28/58
33	.709945	33	.953788	33	204	49	39-18/58
34	.757777	34	.928429	34	211	2	4- 8/58
35	.802587	35	.898047	35	217	14	28-56/58
36	.843850	36	.862998	36	223	26	53-46/58
37	.881081	37	.823695	37	229	39	18-36/58
38	.913845	38	.780594	38	235	51	43-26/58
39	.941756	39	.734204	39	242	4	8-16/58
40	.964488	40	.685069	40	248	16	33- 6/58
41	.981775	41	.633764	41	254	28	57-54/58
42	.993413	42	.580891	42	260	41	22-44/58
43	.999267	43	.527070	43	266	53	47-34/58
44	.999267	44	.472931	44	273	6	12-24/58
45	.993413	45	.419109	45	279	18	37-14/58
46	.981775	46	.366236	46	285	31	2- 4/58
47	.964488	47	.314931	47	291	43	26-52/58
48	.941756	48	.265796	48	297	55	51-42/58
49	.913845	49	.219407	49	304	8	16-32/58
50	.881081	50	.176305	50	310	20	41-22/58
51	.843850	51	.137002	51	316	33	6-12/58
52	.802587	52	.101954	52	322	45	31- 2/58
53	.757777	53	.071571	53	328	57	55-50/58
54	.709945	54	.046212	54	335	10	20-40/58
55	.659651	55	.026173	55	341	22	45-30/58
56	.607485	56	.011689	56	347	35	10-20/58
57	.554060	57	.002931	57	353	47	35-10/58
58	.500000	58	.000000	58	360	0	0

59 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

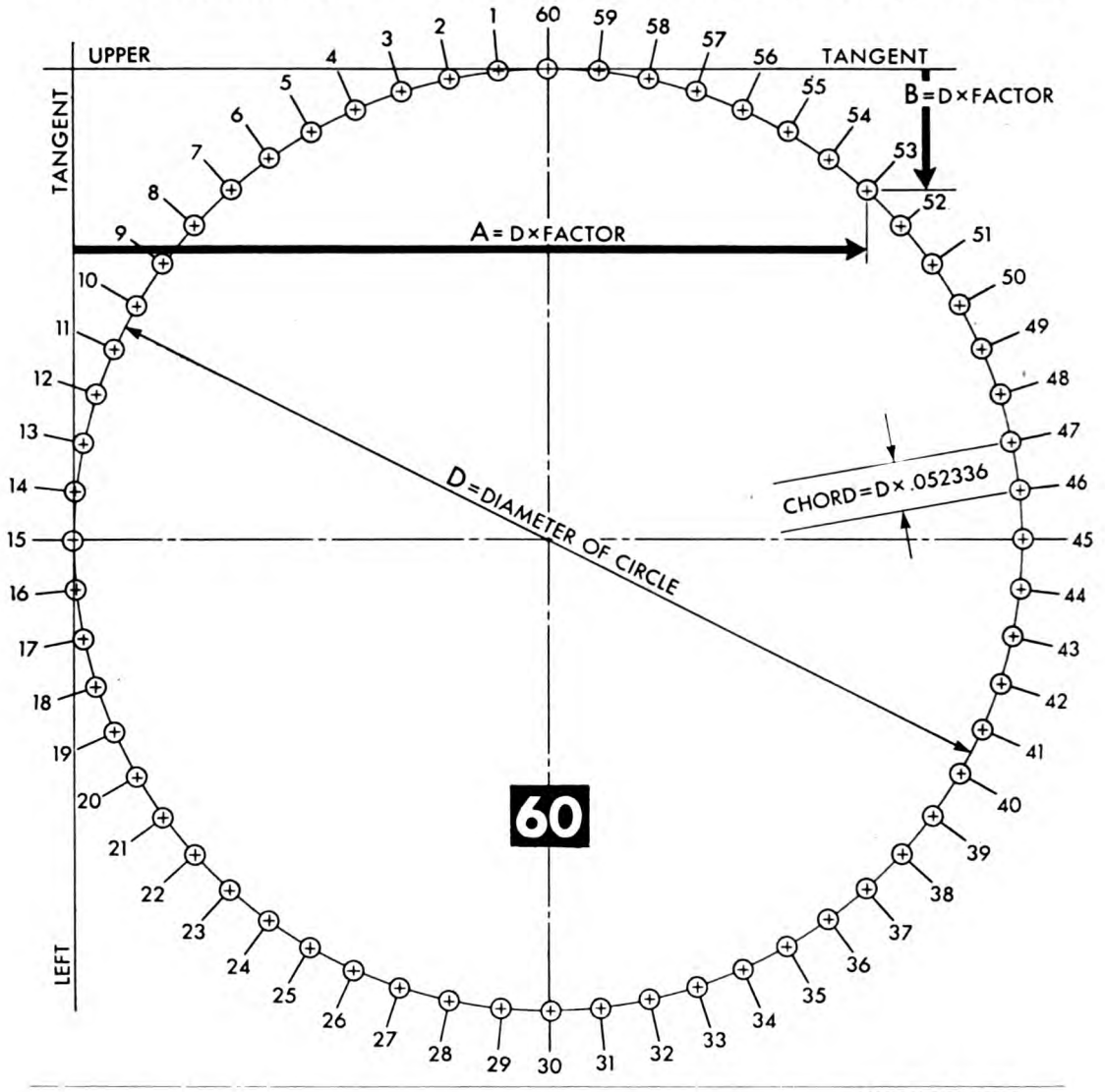


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.446853	1	.002833	1	6	6– 6/59
2	.394309	2	.011298	2	12	12–12/59
3	.342962	3	.025301	3	18	18–18/59
4	.293394	4	.044682	4	24	24–24/59
5	.246167	5	.069223	5	30	30–30/59
6	.201816	6	.098644	6	36	36–36/59
7	.160844	7	.132613	7	42	42–42/59
8	.123715	8	.170744	8	48	48–48/59
9	.090849	9	.212606	9	54	54–54/59
10	.062619	10	.257725	10	61	1– 1/59
11	.039344	11	.305588	11	67	7– 7/59
12	.021289	12	.355654	12	73	13–13/59

COORDINATE FACTORS AND ANGLES—59 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
13	.008658	13	.407356	13	79	19	19–19/59
14	.001594	14	.460107	14	85	25	25–25/59
15	.000177	15	.513310	15	91	31	31–31/59
16	.004424	16	.566363	16	97	37	37–37/59
17	.014285	17	.618663	17	103	43	43–43/59
18	.029650	18	.669619	18	109	49	49–49/59
19	.050344	19	.718654	19	115	55	55–55/59
20	.076133	20	.765210	20	122	2	2– 2/59
21	.106724	21	.808762	21	128	8	8– 8/59
22	.141772	22	.848816	22	134	14	14–14/59
23	.180878	23	.884917	23	140	20	20–20/59
24	.223600	24	.916657	24	146	26	26–26/59
25	.269454	25	.943676	25	152	32	32–32/59
26	.317920	26	.965668	26	158	38	38–38/59
27	.368449	27	.982384	27	164	44	44–44/59
28	.420469	28	.993634	28	170	50	50–50/59
29	.473389	29	.999291	29	176	56	56–56/59
30	.526611	30	.999291	30	183	3	3– 3/59
31	.579532	31	.993634	31	189	9	9– 9/59
32	.631551	32	.982384	32	195	15	15–15/59
33	.682080	33	.965668	33	201	21	21–21/59
34	.730546	34	.943676	34	207	27	27–27/59
35	.776400	35	.916657	35	213	33	33–33/59
36	.819122	36	.884917	36	219	39	39–39/59
37	.858228	37	.848816	37	225	45	45–45/59
38	.893276	38	.808762	38	231	51	51–51/59
39	.923867	39	.765210	39	237	57	57–57/59
40	.949656	40	.718654	40	244	4	4– 4/59
41	.970350	41	.669619	41	250	10	10–10/59
42	.985715	42	.618663	42	256	16	16–16/59
43	.995576	43	.566363	43	262	22	22–22/59
44	.999823	44	.513310	44	268	28	28–28/59
45	.998406	45	.460107	45	274	34	34–34/59
46	.991342	46	.407356	46	280	40	40–40/59
47	.978711	47	.355654	47	286	46	46–46/59
48	.960656	48	.305588	48	292	52	52–52/59
49	.937382	49	.257725	49	298	58	58–58/59
50	.909151	50	.212606	50	305	5	5– 5/59
51	.876285	51	.170744	51	311	11	11–11/59
52	.839156	52	.132613	52	317	17	17–17/59
53	.798184	53	.098644	53	323	23	23–23/59
54	.753833	54	.069223	54	329	29	29–29/59
55	.706606	55	.044682	55	335	35	35–35/59
56	.657038	56	.025301	56	341	41	41–41/59
57	.605691	57	.011298	57	347	47	47–47/59
58	.553147	58	.002833	58	353	53	53–53/59
59	.500000	59	.000000	59	360	0	0

60 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

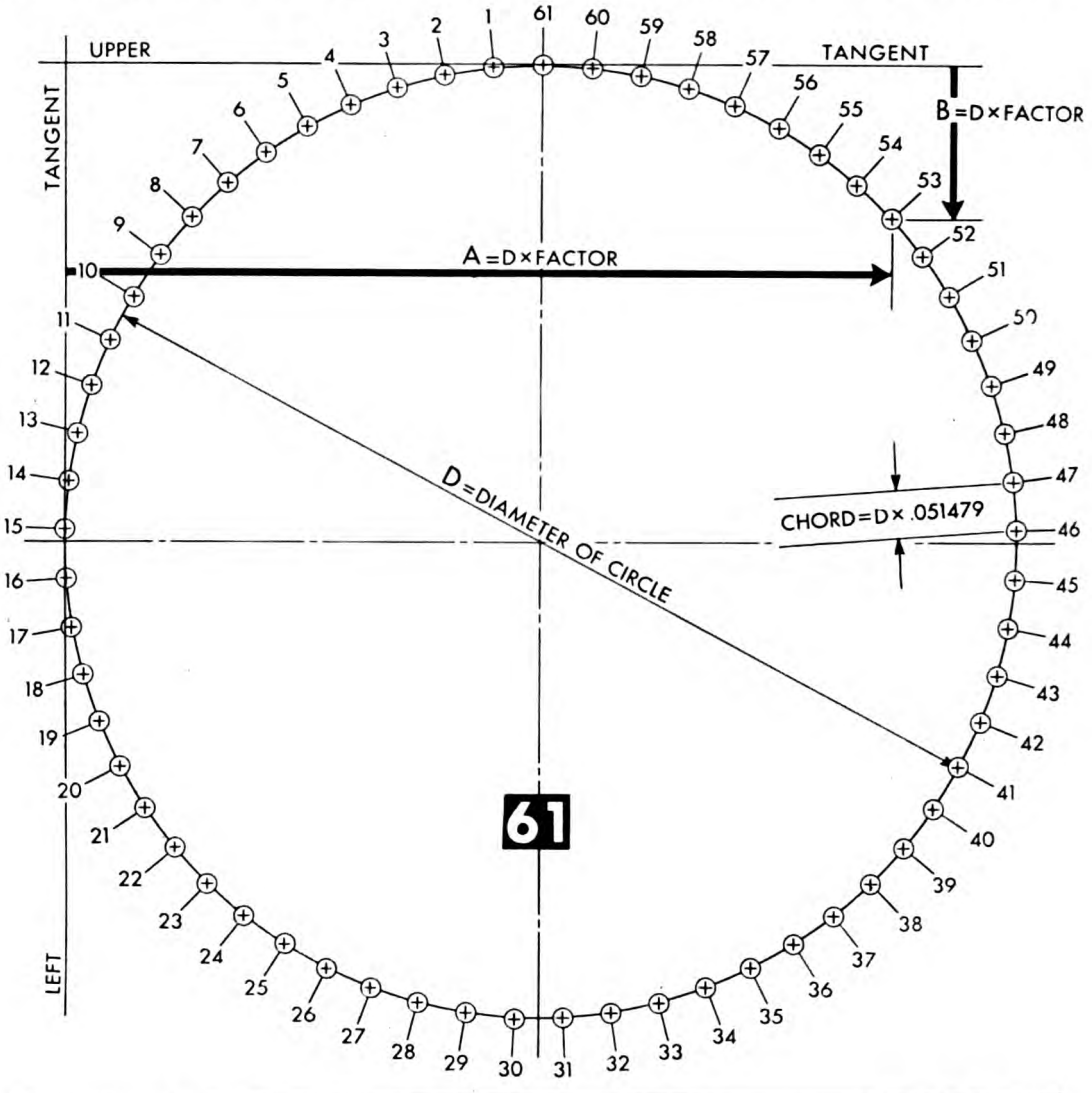


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.447736	1	.002739	1	6	0	0
2	.396044	2	.010926	2	12	0	0
3	.345492	3	.024472	3	18	0	0
4	.296632	4	.043227	4	24	0	0
5	.250000	5	.066988	5	30	0	0
6	.206107	6	.095492	6	36	0	0
7	.165435	7	.128428	7	42	0	0
8	.128428	8	.165435	8	48	0	0
9	.095492	9	.206107	9	54	0	0
10	.066987	10	.250000	10	60	0	0
11	.043227	11	.296632	11	66	0	0
12	.024472	12	.345492	12	72	0	0

COORDINATE FACTORS AND ANGLES—60 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
13	.010926	13	.396044	13	78	0	0
14	.002739	14	.447736	14	84	0	0
15	.000000	15	.500000	15	90	0	0
16	.002739	16	.552264	16	96	0	0
17	.010926	17	.603956	17	102	0	0
18	.024472	18	.654509	18	108	0	0
19	.043227	19	.703368	19	114	0	0
20	.066987	20	.750000	20	120	0	0
21	.095492	21	.793893	21	126	0	0
22	.128428	22	.834565	22	132	0	0
23	.165435	23	.871572	23	138	0	0
24	.206107	24	.904509	24	144	0	0
25	.250000	25	.933013	25	150	0	0
26	.296632	26	.956773	26	156	0	0
27	.345492	27	.975528	27	162	0	0
28	.396044	28	.989074	28	168	0	0
29	.447736	29	.997261	29	174	0	0
30	.500000	30	1.000000	30	180	0	0
31	.552264	31	.997261	31	186	0	0
32	.603956	32	.989074	32	192	0	0
33	.654509	33	.975528	33	198	0	0
34	.703368	34	.956773	34	204	0	0
35	.750000	35	.933013	35	210	0	0
36	.793893	36	.904509	36	216	0	0
37	.834565	37	.871572	37	222	0	0
38	.871572	38	.834565	38	228	0	0
39	.904509	39	.793893	39	234	0	0
40	.933013	40	.750000	40	240	0	0
41	.956773	41	.703368	41	246	0	0
42	.975528	42	.654509	42	252	0	0
43	.989074	43	.603956	43	258	0	0
44	.997261	44	.552264	44	264	0	0
45	1.000000	45	.500000	45	270	0	0
46	.997261	46	.447736	46	276	0	0
47	.989074	47	.396044	47	282	0	0
48	.975528	48	.345492	48	288	0	0
49	.956773	49	.296632	49	294	0	0
50	.933013	50	.250000	50	300	0	0
51	.904509	51	.206107	51	306	0	0
52	.871572	52	.165435	52	312	0	0
53	.834565	53	.128428	53	318	0	0
54	.793893	54	.095492	54	324	0	0
55	.750000	55	.066988	55	330	0	0
56	.703368	56	.043227	56	336	0	0
57	.654509	57	.024472	57	342	0	0
58	.603956	58	.010926	58	348	0	0
59	.552264	59	.002739	59	354	0	0
60	.500000	60	.000000	60	360	0	0

61 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

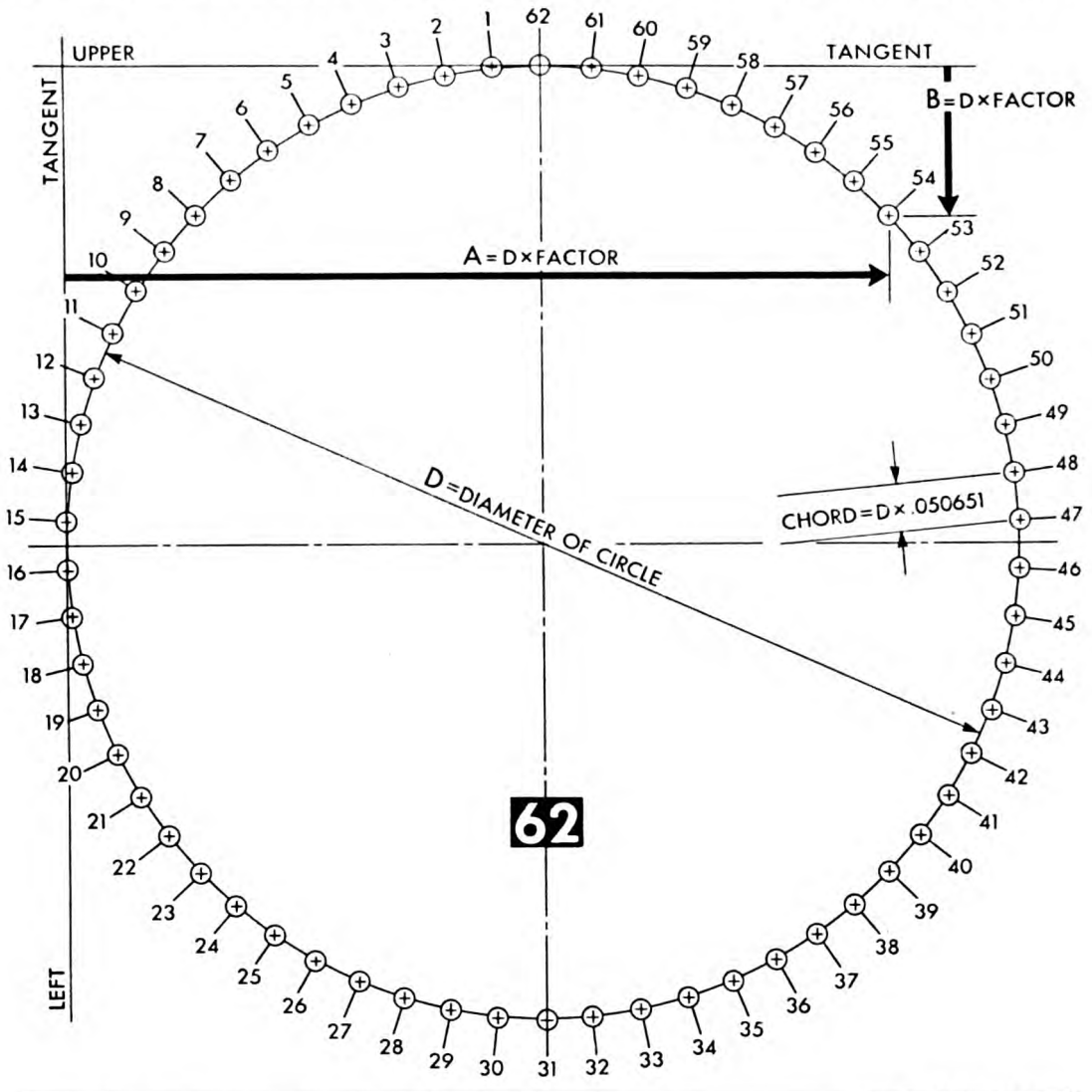


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.448590	1	.002650	1	5	54	5–55/61
2	.397724	2	.010572	2	11	48	11–49/61
3	.347943	3	.023682	3	17	42	17–43/61
4	.299773	4	.041842	4	23	36	23–37/61
5	.253726	5	.064857	5	29	30	29–31/61
6	.210290	6	.092486	6	35	24	35–25/61
7	.169924	7	.124434	7	41	18	41–19/61
8	.133057	8	.160363	8	47	12	47–13/61
9	.100080	9	.199893	9	53	6	53– 7/61
10	.071343	10	.242604	10	59	00	59– 1/61
11	.047149	11	.288043	11	64	55	4–56/61
12	.027755	12	.355729	12	70	49	10–50/61

COORDINATE FACTORS AND ANGLES—61 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
13	.013368	13	.385156	13	76	43	16–44/61
14	.004139	14	.435801	14	82	37	22–38/61
15	.000166	15	.487126	15	88	31	28–32/61
16	.001491	16	.538588	16	94	25	34–26/61
17	.008101	17	.589640	17	100	19	40–20/61
18	.019925	18	.639743	18	106	13	46–14/61
19	.036838	19	.688364	19	112	7	52– 8/61
20	.058661	20	.734988	20	118	1	58– 2/61
21	.085162	21	.779122	21	123	56	3–57/61
22	.116060	22	.820297	22	129	50	9–51/61
23	.151028	23	.858076	23	135	44	15–45/61
24	.189695	24	.892060	24	141	38	21–39/61
25	.231652	25	.921888	25	147	32	27–33/61
26	.276453	26	.947244	26	153	26	33–27/61
27	.323624	27	.967859	27	159	20	39–21/61
28	.372664	28	.983514	28	165	14	45–15/61
29	.423055	29	.994044	29	171	8	51– 9/61
30	.474261	30	.999337	30	177	2	57– 3/61
31	.525739	31	.999337	31	182	57	2–58/61
32	.576945	32	.994044	32	188	51	8–52/61
33	.627336	33	.983514	33	194	45	14–46/61
34	.676376	34	.967859	34	200	39	20–40/61
35	.723547	35	.947244	35	206	33	26–34/61
36	.768348	36	.921888	36	212	27	32–28/61
37	.810305	37	.892060	37	218	21	38–22/61
38	.848972	38	.858076	38	224	15	44–16/61
39	.883940	39	.820297	39	230	9	50–10/61
40	.914839	40	.779122	40	236	3	56– 4/61
41	.941339	41	.734988	41	241	58	1–59/61
42	.963162	42	.688364	42	247	52	7–53/61
43	.980075	43	.639743	43	253	46	13–47/61
44	.991899	44	.589640	44	259	40	19–41/61
45	.998509	45	.538588	45	265	34	25–35/61
46	.999834	46	.487126	46	271	28	31–29/61
47	.995861	47	.435801	47	277	22	37–23/61
48	.986632	48	.385156	48	283	16	43–17/61
49	.972245	49	.335729	49	289	10	49–11/61
50	.952851	50	.288043	50	295	4	55– 5/61
51	.928657	51	.242604	51	300	59	00–60/61
52	.899920	52	.199893	52	306	53	6–54/61
53	.866943	53	.160363	53	312	47	12–48/61
54	.830076	54	.124434	54	318	41	18–42/61
55	.789711	55	.092486	55	324	35	24–36/61
56	.746274	56	.064857	56	330	29	30–30/61
57	.700227	57	.041842	57	336	23	36–24/61
58	.652057	58	.023682	58	342	17	42–18/61
59	.602276	59	.010572	59	348	11	48–12/61
60	.551410	60	.002650	60	354	5	54– 6/61
61	.500000	61	.000000	61	360	0	0

62 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

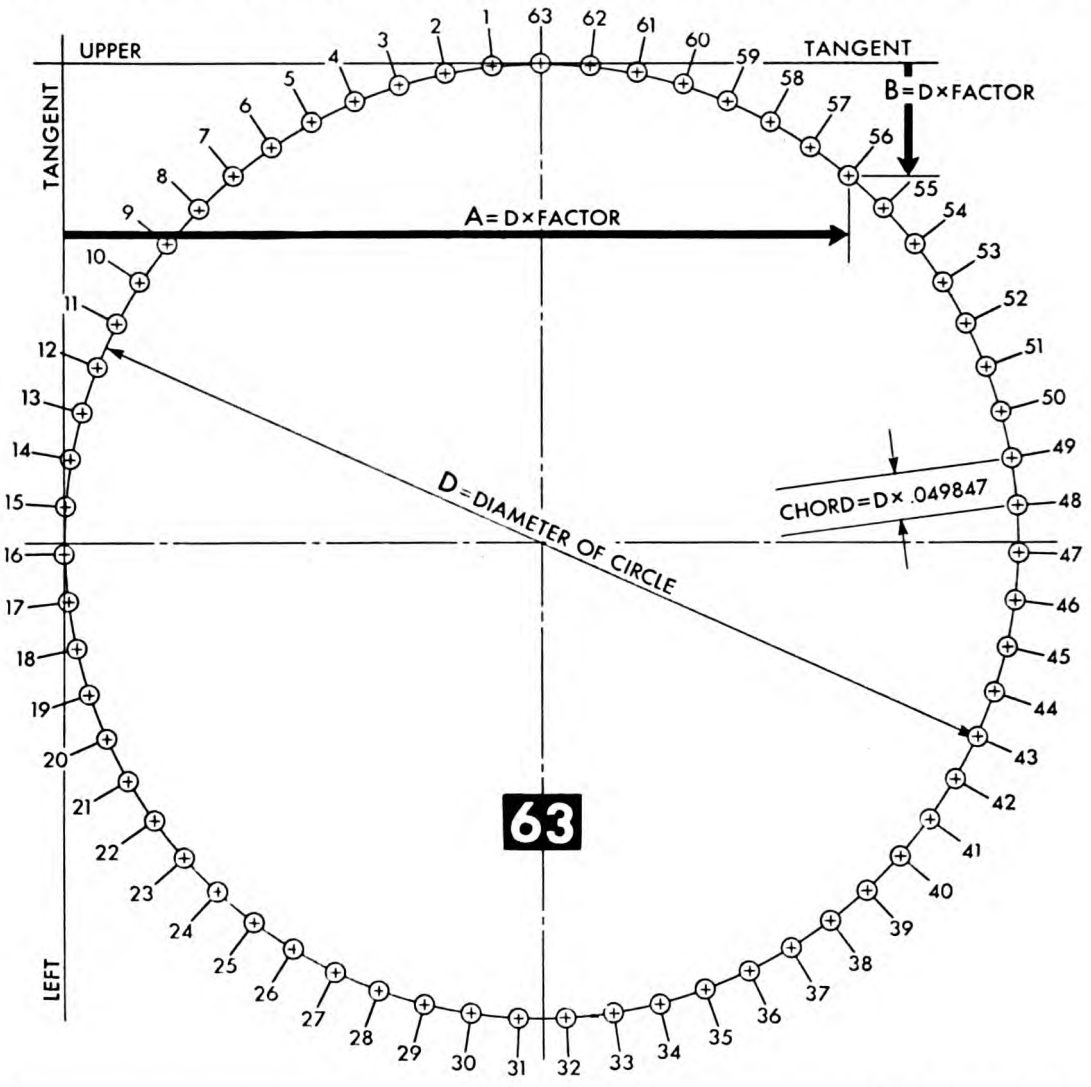


→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE DEG.	MIN.	SEC.
1 .449416	1 .002565	1	5	48	23-14/62
2 .399351	2 .010235	2	11	36	46-28/62
3 .350318	3 .022930	3	17	25	9-42/62
4 .302822	4 .040521	4	23	13	32-56/62
5 .257349	5 .062827	5	29	1	56- 8/62
6 .214366	6 .089618	6	34	50	19-22/62
7 .174314	7 .120621	7	40	38	42-36/62
8 .137606	8 .155517	8	46	27	5-50/62
9 .104612	9 .193947	9	52	15	29- 2/62
10 .075678	10 .235518	10	58	3	52-16/62
11 .051098	11 .279803	11	63	52	15-30/62
12 .031124	12 .326347	12	69	40	38-44/62
13 .015961	13 .374674	13	75	29	1-58/62

COORDINATE FACTORS AND ANGLES—62 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.005766	14	.424286	14	81	17	25–10/62
15	.000642	15	.474675	15	87	5	48–24/62
16	.000642	16	.525325	16	92	54	11–38/62
17	.005766	17	.575714	17	98	42	34–52/62
18	.015961	18	.625326	18	104	30	58– 4/62
19	.031124	19	.673653	19	110	19	21–18/62
20	.051098	20	.720197	20	116	7	44–32/62
21	.075678	21	.764482	21	121	56	7–46/62
22	.104612	22	.806053	22	127	44	30–60/62
23	.137606	23	.844484	23	133	32	54–12/62
24	.174314	24	.879379	24	139	21	17–26/62
25	.214366	25	.910382	25	145	9	40–40/62
26	.257349	26	.937173	26	150	58	3–54/62
27	.302822	27	.959479	27	156	46	27– 6/62
28	.350318	28	.977070	28	162	34	50–20/62
29	.399351	29	.989765	29	168	23	13–34/62
30	.449416	30	.997435	30	174	11	36–48/62
31	.500000	31	1.000000	31	180	00	00000000
32	.550584	32	.997435	32	185	48	23–14/62
33	.600649	33	.989765	33	191	36	46–28/62
34	.649682	34	.977070	34	197	25	9–42/62
35	.697178	35	.959479	35	203	13	32–56/62
36	.742651	36	.937173	36	209	1	56– 8/62
37	.785634	37	.910382	37	214	50	19–22/62
38	.825686	38	.879379	38	220	38	42–36/62
39	.862394	39	.844484	39	226	27	5–50/62
40	.895388	40	.806053	40	232	15	29– 2/62
41	.924322	41	.764482	41	238	3	52–16/62
42	.948902	42	.720197	42	243	52	15–30/62
43	.968876	43	.673653	43	249	40	38–44/62
44	.984039	44	.625326	44	255	29	1–58/62
45	.994234	45	.575714	45	261	17	25–10/62
46	.999358	46	.525325	46	267	5	48–24/62
47	.999358	47	.474675	47	272	54	11–38/62
48	.994234	48	.424286	48	278	42	34–52/62
49	.984039	49	.374674	49	284	30	58– 4/62
50	.968876	50	.326347	50	290	19	21–18/62
51	.948902	51	.279803	51	296	7	44–32/62
52	.924322	52	.235518	52	301	56	7–46/62
53	.895388	53	.193947	53	307	44	30–60/62
54	.862394	54	.155517	54	313	32	54–12/62
55	.825686	55	.120621	55	319	21	17–26/62
56	.785634	56	.089618	56	325	9	40–40/62
57	.742651	57	.062827	57	330	58	3–54/62
58	.697178	58	.040521	58	336	46	27– 6/62
59	.649682	59	.022930	59	342	34	50–20/62
60	.600649	60	.010235	60	348	23	13–34/62
61	.550584	61	.002565	61	354	11	36–48/62
62	.500000	62	.000000	62	360	0	0

63 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

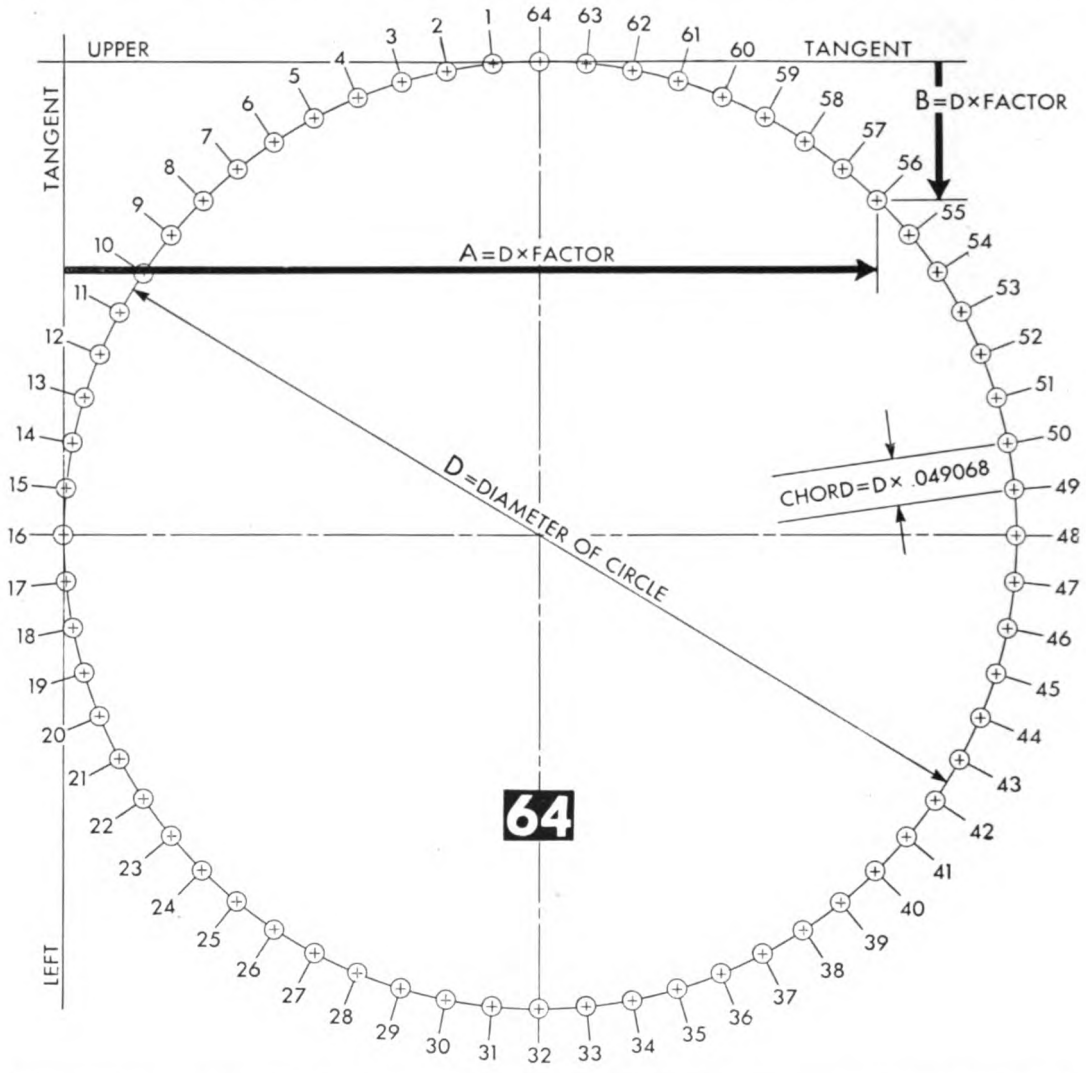


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.450216	1	.002485	1	5	42	51-27/63
2	.400927	2	.009914	2	11	25	42-54/63
3	.352622	3	.022214	3	17	8	34-18/63
4	.305783	4	.039262	4	22	51	25-45/63
5	.260873	5	.060889	5	28	34	17- 9/63
6	.218340	6	.086881	6	34	17	8-36/63
7	.178606	7	.116978	7	40	00	00000000
8	.142067	8	.150882	8	45	42	51-27/63
9	.109084	9	.188255	9	51	25	42-54/63
10	.079987	10	.228727	10	57	8	34-18/63
11	.055064	11	.271895	11	62	51	25-45/63
12	.034563	12	.317330	12	68	34	17- 9/63
13	.018688	13	.364580	13	74	17	8-36/63

COORDINATE FACTORS AND ANGLES—63 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.007596	14	.413176	14	80	00	00000000
15	.001398	15	.462635	15	85	42	51-27/63
16	.000155	16	.512465	16	91	25	42-54/63
17	.003880	17	.562172	17	97	8	34-18/63
18	.012536	18	.611260	18	102	51	25-45/63
19	.026036	19	.659243	19	108	34	17- 9/63
20	.044247	20	.705644	20	114	17	8-36/63
21	.066987	21	.750000	21	120	00	00000000
22	.094031	22	.791872	22	125	42	51-27/63
23	.125109	23	.830843	23	131	25	42-54/63
24	.159914	24	.866526	24	137	8	34-18/63
25	.198098	25	.898566	25	142	51	25-45/63
26	.239282	26	.926645	26	148	34	17- 9/63
27	.283058	27	.950484	27	154	17	8-36/63
28	.328990	28	.969846	28	160	00	00000000
29	.376621	29	.984539	29	165	42	51-27/63
30	.425479	30	.994415	30	171	25	42-54/63
31	.475077	31	.999379	31	177	8	34-18/63
32	.524923	32	.999379	32	182	51	25-45/63
33	.574521	33	.994415	33	188	34	17- 9/63
34	.623379	34	.984539	34	194	17	8-36/63
35	.671010	35	.969846	35	200	00	00000000
36	.716942	36	.950484	36	205	42	51-27/63
37	.760718	37	.926645	37	211	25	42-54/63
38	.801902	38	.898566	38	217	8	34-18/63
39	.840086	39	.866526	39	222	51	25-45/63
40	.874891	40	.830843	40	228	34	17- 9/63
41	.905969	41	.791872	41	234	17	8-36/63
42	.933013	42	.750000	42	240	00	00000000
43	.955753	43	.705644	43	245	42	51-27/63
44	.973964	44	.659243	44	251	25	42-54/63
45	.987464	45	.611260	45	257	8	34-18/63
46	.996120	46	.562172	46	262	51	25-45/63
47	.999845	47	.512465	47	268	34	17- 9/63
48	.998602	48	.462635	48	274	17	8-36/63
49	.992404	49	.413176	49	280	00	00000000
50	.981312	50	.364580	50	285	42	51-27/63
51	.965437	51	.317330	51	291	25	42-54/63
52	.944936	52	.271895	52	297	8	34-18/63
53	.920013	53	.228727	53	302	51	25-45/63
54	.890916	54	.188255	54	308	34	17- 9/63
55	.857933	55	.150882	55	314	17	8-36/63
56	.821394	56	.116978	56	320	00	00000000
57	.781660	57	.086881	57	325	42	51-27/63
58	.739127	58	.060889	58	331	25	42-54/63
59	.694217	59	.039262	59	337	8	34-18/63
60	.647378	60	.022214	60	342	51	25-45/63
61	.599073	61	.009914	61	348	34	17- 9/63
62	.549784	62	.002485	62	354	17	8-36/63
63	.500000	63	.000000	63	360	0	0

64 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

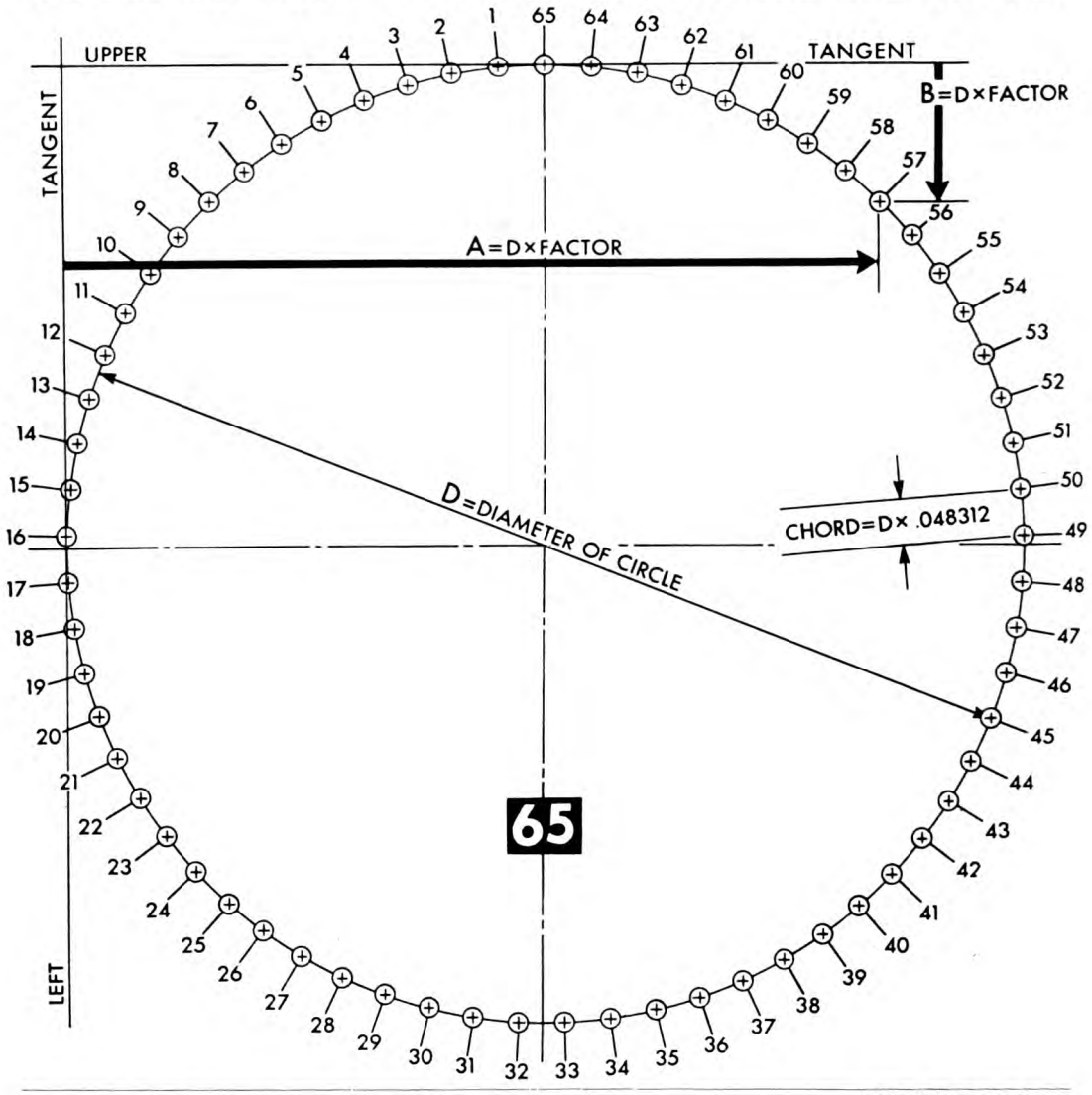


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.450992	1	.002408	1	5	37	30
2	.402455	2	.009607	2	11	15	00
3	.354858	3	.021530	3	16	52	30
4	.308658	4	.038060	4	22	30	00
5	.264302	5	.059039	5	28	7	30
6	.222215	6	.084265	6	33	45	00
7	.182803	7	.113495	7	39	22	30
8	.146447	8	.146447	8	45	00	00
9	.113495	9	.182803	9	50	37	30
10	.084265	10	.222215	10	56	15	00
11	.059039	11	.264302	11	61	52	30
12	.038060	12	.308658	12	67	30	00
13	.021530	13	.354858	13	73	7	30

COORDINATE FACTORS AND ANGLES—64 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.009607	14	.402455	14	78	45	00
15	.002408	15	.450992	15	84	22	30
16	.000000	16	.500000	16	90	00	00
17	.002408	17	.549009	17	95	37	30
18	.009607	18	.597545	18	101	15	00
19	.021530	19	.645142	19	106	52	30
20	.038060	20	.691342	20	112	30	00
21	.059039	21	.735698	21	118	7	30
22	.084265	22	.777785	22	123	45	00
23	.113495	23	.817197	23	129	22	30
24	.146447	24	.853553	24	135	00	00
25	.182803	25	.886505	25	140	37	30
26	.222215	26	.915735	26	146	15	00
27	.264302	27	.940961	27	151	52	30
28	.308658	28	.961940	28	157	30	00
29	.354858	29	.978470	29	163	7	30
30	.402455	30	.990393	30	168	45	00
31	.450992	31	.997592	31	174	22	30
32	.500000	32	1.000000	32	180	00	00
33	.549009	33	.997592	33	185	37	30
34	.597545	34	.990393	34	191	15	00
35	.645142	35	.978470	35	196	52	30
36	.691342	36	.961940	36	202	30	00
37	.735698	37	.940961	37	208	7	30
38	.777785	38	.915735	38	213	45	00
39	.817197	39	.886505	39	219	22	30
40	.853553	40	.853553	40	225	00	00
41	.886505	41	.817197	41	230	37	30
42	.915735	42	.777785	42	236	15	00
43	.940961	43	.735698	43	241	52	30
44	.961940	44	.691342	44	247	30	00
45	.978470	45	.645142	45	253	7	30
46	.990393	46	.597545	46	258	45	00
47	.997592	47	.549009	47	264	22	30
48	1.000000	48	.500000	48	270	00	00
49	.997592	49	.450992	49	275	37	30
50	.990393	50	.402455	50	281	15	00
51	.978470	51	.354858	51	286	52	30
52	.961940	52	.308658	52	292	30	00
53	.940961	53	.264302	53	298	7	30
54	.915735	54	.222215	54	303	45	00
55	.886505	55	.182803	55	309	22	30
56	.853553	56	.146447	56	315	00	00
57	.817197	57	.113495	57	320	37	30
58	.777785	58	.084265	58	326	15	00
59	.735698	59	.059039	59	331	52	30
60	.691342	60	.038060	60	337	30	00
61	.645142	61	.021530	61	343	7	30
62	.597545	62	.009607	62	348	45	00
63	.549009	63	.002408	63	354	22	30
64	.500000	64	.000000	64	360	00	00

65 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

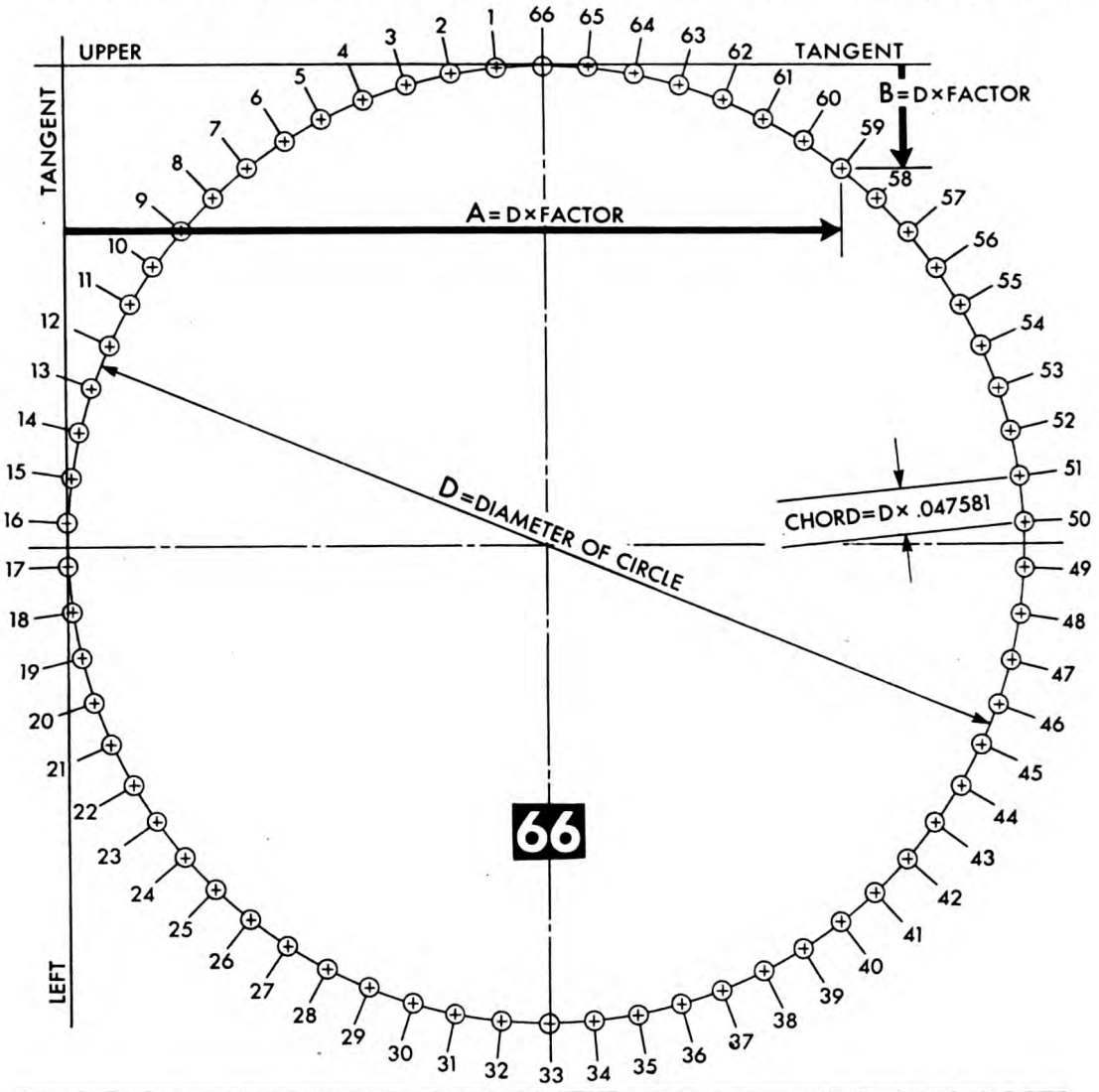


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.451743	1	.002334	1	5	32	18–30/65
2	.403937	2	.009315	2	11	4	36–60/65
3	.357027	3	.020877	3	16	36	55–25/65
4	.311453	4	.036913	4	22	9	13–55/65
5	.267638	5	.057272	5	27	41	32–20/65
6	.225994	6	.081765	6	33	13	50–50/65
7	.186907	7	.110163	7	38	46	9–15/65
8	.150744	8	.142201	8	44	18	27–45/65
9	.117842	9	.177579	9	49	50	46–10/65
10	.088508	10	.215968	10	55	23	4–40/65
11	.063016	11	.257008	11	60	55	23– 5/65
12	.041604	12	.300318	12	66	27	41–35/65
13	.024472	13	.345492	13	72	00	00000000

COORDINATE FACTORS AND ANGLES—65 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
14	.011780	14	.392108	14	77	32	18-30/65
15	.003646	15	.439732	15	83	4	36-60/65
16	.000146	16	.487918	16	88	36	55-25/65
17	.001313	17	.536217	17	94	9	13-55/65
18	.007137	18	.584179	18	99	41	32-20/65
19	.017562	19	.631354	19	105	13	50-50/65
20	.032492	20	.677302	20	110	46	9-15/65
21	.051787	21	.721596	21	116	18	27-45/65
22	.075266	22	.763820	22	121	50	46-10/65
23	.102711	23	.803581	23	127	23	4-40/65
24	.133866	24	.840508	24	132	55	23- 5/65
25	.168439	25	.874255	25	138	27	41-35/65
26	.206107	26	.904509	26	144	00	00000000
27	.246520	27	930985	27	149	32	18-30/65
28	.289299	28	.953437	28	155	4	36-60/65
29	.334046	29	.971656	29	160	36	55-25/65
30	.380342	30	.985471	30	166	9	13-55/65
31	.427755	31	.994753	31	171	41	32-20/65
32	.475843	32	.999416	32	177	13	50-50/65
33	.524158	33	.999416	33	182	46	9-15/65
34	.572245	34	.994753	34	188	18	27-45/65
35	.619658	35	.985471	35	193	50	46-10/65
36	.665954	36	.971656	36	199	23	4-40/65
37	.710701	37	.953437	37	204	55	23- 5/65
38	.753480	38	.930985	38	210	27	41-35/65
39	.793893	39	.904509	39	216	00	00000000
40	.831561	40	.874255	40	221	32	18-30/65
41	.866134	41	.840508	41	227	4	36-60/65
42	.897289	42	.803581	42	232	36	55-25/65
43	.924734	43	.763820	43	238	9	13-55/65
44	.948214	44	.721596	44	243	41	32-20/65
45	.967508	45	.677302	45	249	13	50-50/65
46	.982438	46	.631354	46	254	46	9-15/65
47	.992863	47	.584179	47	260	18	27-45/65
48	.998687	48	.536217	48	265	50	46-10/65
49	.999854	49	.487918	49	271	23	4-40/65
50	.996354	50	.439732	50	276	55	23- 5/65
51	.988221	51	.392108	51	282	27	41-35/65
52	.975528	52	.345492	52	288	00	00000000
53	.958396	53	.300318	53	293	32	18-30/65
54	.936984	54	.257008	54	299	4	36-60/65
55	.911492	55	.215968	55	304	36	55-25/65
56	.882158	56	.177579	56	310	9	13-55/65
57	.849256	57	.142201	57	315	41	32-20/65
58	.813093	58	.110163	58	321	13	50-50/65
59	.774006	59	.081765	59	326	46	9-15/65
60	.732362	60	.057272	60	332	18	27-45/65
61	.688547	61	.036913	61	337	50	46-10/65
62	.642973	62	.020877	62	343	23	4-40/65
63	.596063	63	.009315	63	348	55	23- 5/65
64	.548257	64	.002334	64	354	27	41-35/65
65	.500000	65	.000000	65	360	0	0

66 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

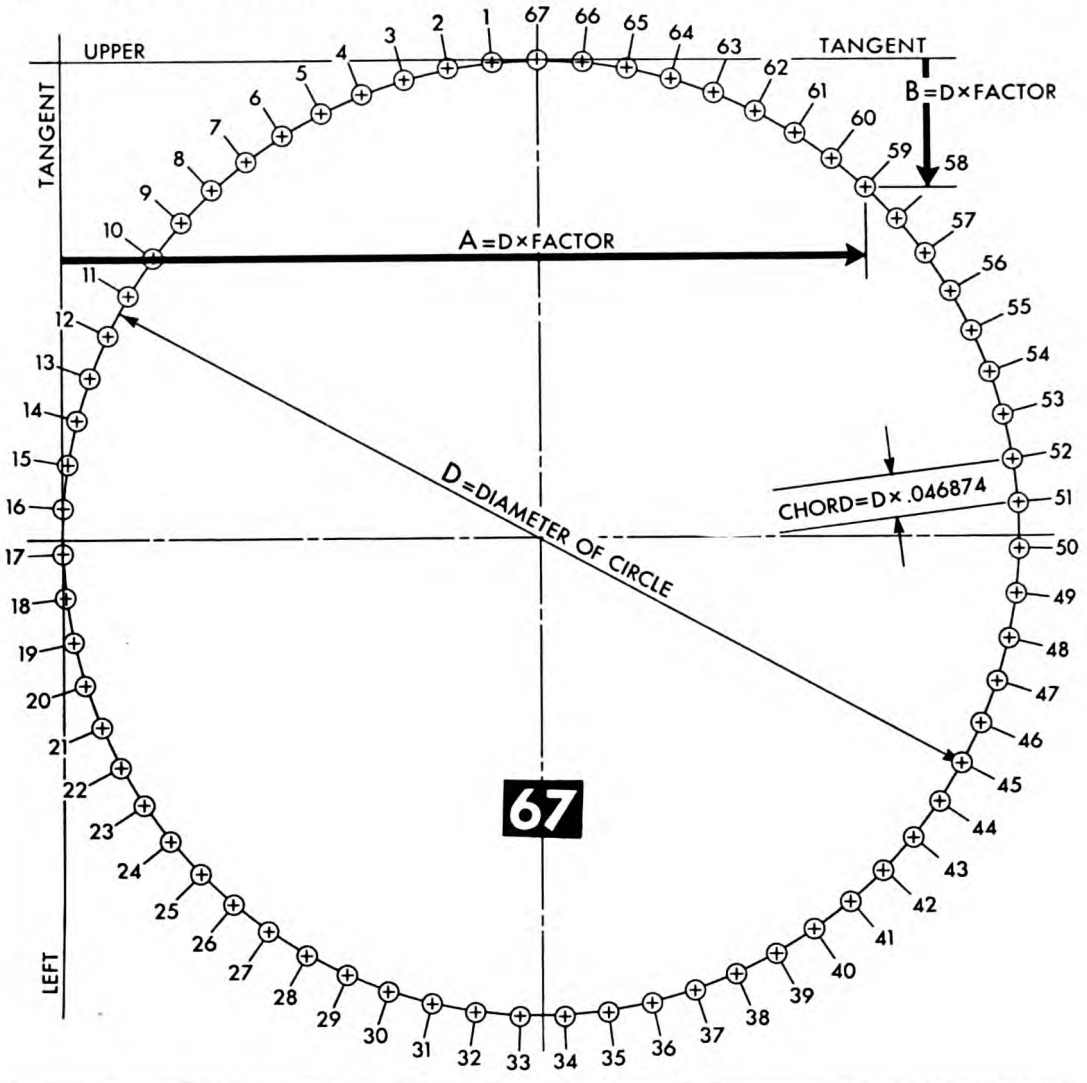


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.452472	1	.002264	1	5	27	16–24/66
2	.405374	2	.009036	2	10	54	32–48/66
3	.359134	3	.020254	3	16	21	49– 6/66
4	.314169	4	.035816	4	21	49	5–30/66
5	.270887	5	.055582	5	27	16	21–54/66
6	.229680	6	.079373	6	32	43	38–12/66
7	.190921	7	.106973	7	38	10	54–36/66
8	.154961	8	.138133	8	43	38	10–60/66
9	.122125	9	.172570	9	49	5	27–18/66
10	.092712	10	.209972	10	54	32	43–42/66
11	.066987	11	.250000	11	60	00	00000000
12	.045184	12	.292293	12	65	27	16–24/66
13	.027500	13	.336466	13	70	54	32–48/66

COORDINATE FACTORS AND ANGLES—66 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
14	.014094	14	.382121	14	76	21	49- 6/66
15	.005089	15	.428843	15	81	49	5-30/66
16	.000566	16	.476209	16	87	16	21-54/66
17	.000566	17	.523791	17	92	43	38-12/66
18	.005089	18	.571157	18	98	10	54-36/66
19	.014094	19	.617880	19	103	38	10-60/66
20	.027500	20	.663534	20	109	5	27-18/66
21	.045184	21	.707708	21	114	32	43-42/66
22	.066987	22	.750000	22	120	00	00000000
23	.092712	23	.790028	23	125	27	16-24/66
24	.122125	24	.827430	24	130	54	32-48/66
25	.154961	25	.861867	25	136	21	49- 6/66
26	.190921	26	.893027	26	141	49	5-30/66
27	.229680	27	.920627	27	147	16	21-54/66
28	.270887	28	.944418	28	152	43	38-12/66
29	.314169	29	.964184	29	158	10	54-36/66
30	.359134	30	.979747	30	163	38	10-60/66
31	.405374	31	.990964	31	169	5	27-18/66
32	.452472	32	.997736	32	174	32	43-42/66
33	.500000	33	1.000000	33	180	00	00000000
34	.547528	34	.997736	34	185	27	16-24/66
35	.594626	35	.990964	35	190	54	32-48/66
36	.640866	36	.979747	36	196	21	49- 6/66
37	.685831	37	.964184	37	201	49	5-30/66
38	.729113	38	.944418	38	207	16	21-54/66
39	.770320	39	.920627	39	212	43	38-12/66
40	.809080	40	.893027	40	218	10	54-36/66
41	.845040	41	.861867	41	223	38	10-60/66
42	.877875	42	.827430	42	229	5	27-18/66
43	.907288	43	.790028	43	234	32	43-42/66
44	.933013	44	.750000	44	240	00	00000000
45	.954816	45	.707708	45	245	27	16-24/66
46	.972500	46	.663534	46	250	54	32-48/66
47	.985906	47	.617880	47	256	21	49- 6/66
48	.994911	48	.571157	48	261	49	5-30/66
49	.999434	49	.523791	49	267	16	21-54/66
50	.999434	50	.476209	50	272	43	38-12/66
51	.994911	51	.428843	51	278	10	54-36/66
52	.985906	52	.382121	52	283	38	10-60/66
53	.972500	53	.336466	53	289	5	27-18/66
54	.954816	54	.292293	54	294	32	43-42/66
55	.933013	55	.250000	55	300	00	00000000
56	.907288	56	.209972	56	305	27	16-24/66
57	.877875	57	.172570	57	310	54	32-48/66
58	.845040	58	.138133	58	316	21	49- 6/66
59	.809080	59	.106973	59	321	49	5-30/66
60	.770320	60	.079373	60	327	16	21-54/66
61	.729113	61	.055582	61	332	43	38-12/66
62	.685831	62	.035816	62	338	10	54-36/66
63	.640866	63	.020254	63	343	38	10-60/66
64	.594626	64	.009036	64	349	5	27-18/66
65	.547528	65	.002264	65	354	32	43-42/66
66	.500000	66	.000000	66	360	0	0

67 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

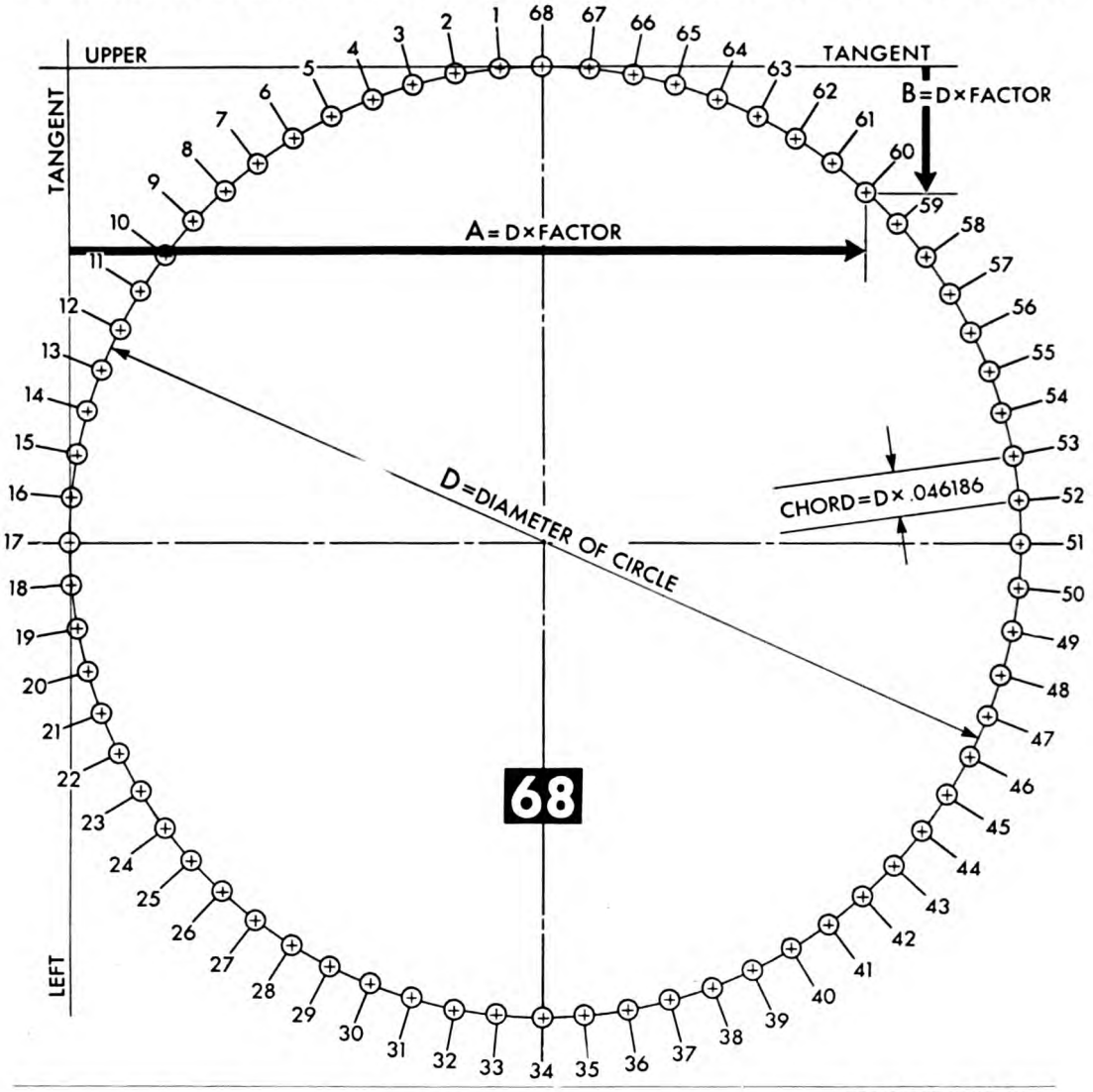


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.453180	1	.002197	1	5	22	23–19/67
2	.406770	2	.008769	2	10	44	46–38/67
3	.361180	3	.019657	3	16	7	9–57/67
4	.316810	4	.034767	4	21	29	33– 9/67
5	.274050	5	.053966	5	26	51	56–28/67
6	.233275	6	.077084	6	32	14	19–47/67
7	.194845	7	.103919	7	37	36	42–66/67
8	.159096	8	.134234	8	42	59	6–18/67
9	.126343	9	.167764	9	48	21	29–37/67
10	.096874	10	.204214	10	53	43	52–56/67
11	.070948	11	.243263	11	59	6	16– 8/67
12	.048792	12	.284568	12	64	28	39–27/67
13	.030601	13	.327767	13	69	51	2–46/67
14	.016535	14	.372479	14	75	13	25–65/67

COORDINATE FACTORS AND ANGLES—67 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
15	.006718	15	.418311	15	80	35 49–17/67
16	.001236	16	.464862	16	85	58 12–36/67
17	.000137	17	.511721	17	91	20 35–55/67
18	.003431	18	.558478	18	96	42 59– 7/67
19	.011089	19	.604720	19	102	5 22–26/67
20	.023044	20	.650042	20	107	27 45–45/67
21	.039190	21	.694046	21	112	50 8–64/67
22	.059385	22	.736344	22	118	12 32–16/67
23	.083453	23	.776566	23	123	34 55–35/67
24	.111181	24	.814356	24	128	57 18–54/67
25	.142327	25	.849385	25	134	19 42– 6/67
26	.176615	26	.881343	26	139	42 5–25/67
27	.213746	27	.909949	27	145	4 28–44/67
28	.253392	28	.934953	28	150	26 51–63/67
29	.295205	29	.956135	29	155	49 15–15/67
30	.338818	30	.973308	30	161	11 38–34/67
31	.383847	31	.986322	31	166	34 1–53/67
32	.429898	32	.995061	32	171	56 25– 5/67
33	.476564	33	.999450	33	177	18 48–24/67
34	.523436	34	.999450	34	182	41 11–43/67
35	.570102	35	.995061	35	188	3 34–62/67
36	.616153	36	.986322	36	193	25 58–14/67
37	.661182	37	.973308	37	198	48 21–33/67
38	.704795	38	.956135	38	204	10 44–52/67
39	.746609	39	.934953	39	209	33 8– 4/67
40	.786255	40	.909949	40	214	55 31–23/67
41	.823385	41	.881343	41	220	17 54–42/67
42	.857674	42	.849385	42	225	40 17–61/67
43	.888819	43	.814356	43	231	2 41–13/67
44	.916547	44	.776566	44	236	25 4–32/67
45	.940615	45	.736344	45	241	47 27–51/67
46	.960810	46	.694046	46	247	9 51– 3/67
47	.976956	47	.650042	47	252	32 14–22/67
48	.988911	48	.604720	48	257	54 37–41/67
49	.996569	49	.558478	49	263	17 00–60/67
50	.999863	50	.511721	50	268	39 24–12/67
51	.998764	51	.464862	51	274	1 47–31/67
52	.993282	52	.418311	52	279	24 10–50/67
53	.983465	53	.372479	53	284	46 34– 2/67
54	.969399	54	.327767	54	290	8 57–21/67
55	.951209	55	.284568	55	295	31 20–40/67
56	.929053	56	.243263	56	300	53 43–59/67
57	.903126	57	.204214	57	306	16 7–11/67
58	.873657	58	.167764	58	311	38 30–30/67
59	.840904	59	.134234	59	317	00 53–49/67
60	.805155	60	.103919	60	322	23 17– 1/67
61	.766725	61	.077084	61	327	45 40–20/67
62	.725950	62	.053966	62	333	8 3–39/67
63	.683190	63	.034767	63	338	30 26–58/67
64	.638820	64	.019657	64	343	52 50–10/67
65	.593230	65	.008769	65	349	15 13–29/67
66	.546820	66	.002197	66	354	37 36–48/67
67	.500000	67	.000000	67	360	0 0

68 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

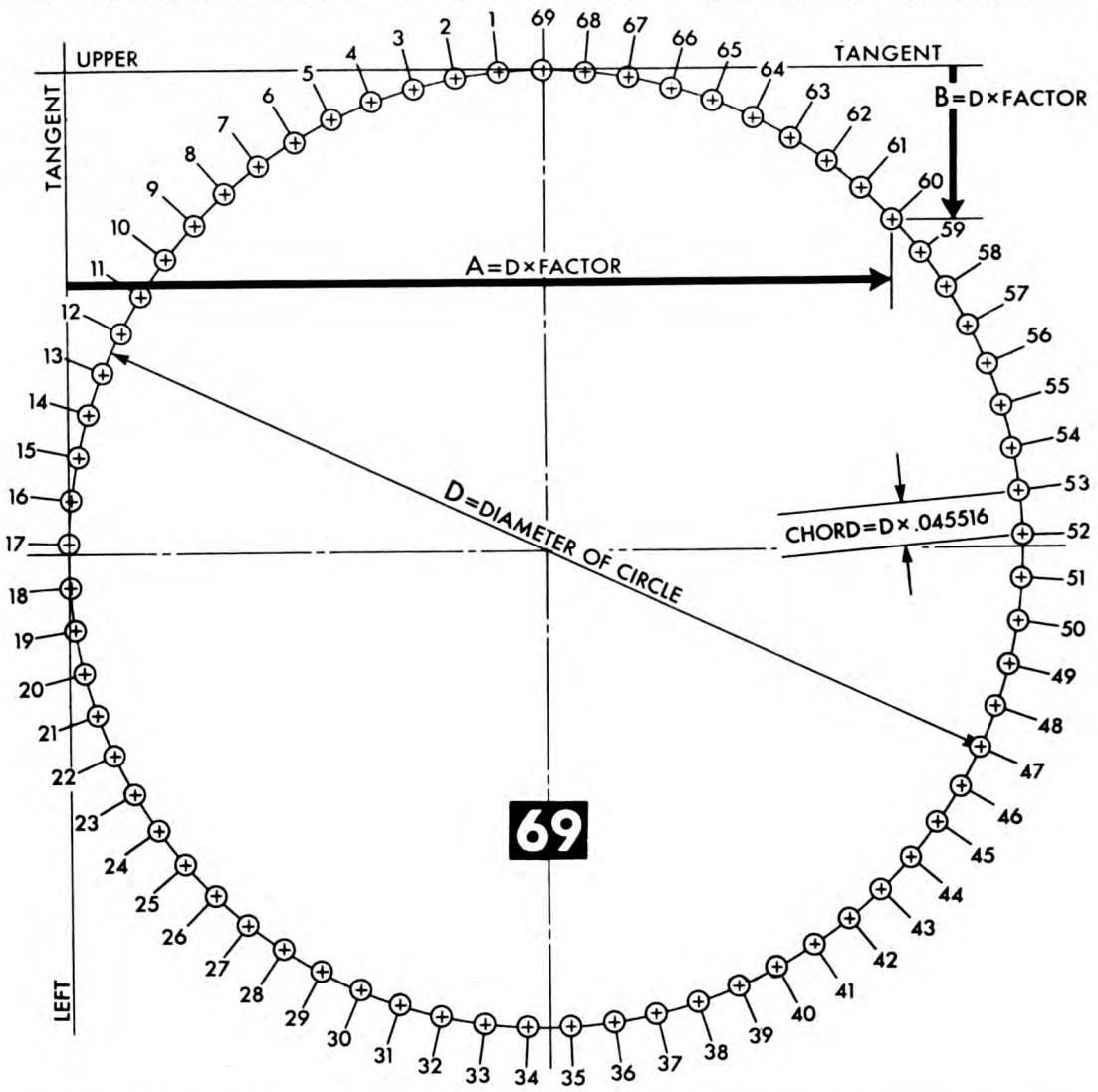


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.453866	1	.002133	1	5	17	38–56/68
2	.408125	2	.008514	2	10	35	17–44/68
3	.363169	3	.019087	3	15	52	56–32/68
4	.319379	4	.033764	4	21	10	35–20/68
5	.277131	5	.052418	5	26	28	14– 8/68
6	.236784	6	.074891	6	31	45	52–64/68
7	.198683	7	.100991	7	37	3	31–52/68
8	.163152	8	.130496	8	42	21	10–40/68
9	.130496	9	.163152	9	47	38	49–28/68
10	.100991	10	.198683	10	52	56	28–16/68
11	.074891	11	.236784	11	58	14	7– 4/68
12	.052418	12	.277131	12	63	31	45–60/68
13	.033764	13	.319379	13	68	49	24–48/68
14	.019087	14	363169	14	74	7	3–36/68

COORDINATE FACTORS AND ANGLES—68 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
15	.008514	15	.408125	15	79	24	42-24/68
16	.002133	16	.453866	16	84	42	21-12/68
17	.000000	17	.500000	17	90	00	00000000
18	.002133	18	.546134	18	95	17	38-56/68
19	.008514	19	.591875	19	100	35	17-44/68
20	.019087	20	.636832	20	105	52	56-32/68
21	.033764	21	.680621	21	111	10	35-20/68
22	.052418	22	.722869	22	116	28	14- 8/68
23	.074891	23	.763216	23	121	45	52-64/68
24	.100991	24	.801317	24	127	3	31-52/68
25	.130496	25	.836848	25	132	21	10-40/68
26	.163152	26	.869504	26	137	38	49-28/68
27	.198683	27	.899009	27	142	56	28-16/68
28	.236784	28	.925109	28	148	14	7- 4/68
29	.277131	29	.947582	29	153	31	45-60/68
30	.319379	30	.966236	30	158	49	24-48/68
31	.363169	31	.980913	31	164	7	3-36/68
32	.408125	32	.991487	32	169	24	42-24/68
33	.453866	33	.997867	33	174	42	21-12/68
34	.500000	34	1.000000	34	180	00	00000000
35	.546134	35	.997867	35	185	17	38-56/68
36	.591875	36	.991487	36	190	35	17-44/68
37	.636832	37	.980913	37	195	52	56-32/68
38	.680621	38	.966236	38	201	10	35-20/68
39	.722869	39	.947582	39	206	28	14- 8/68
40	.763216	40	.925109	40	211	45	52-64/68
41	.801317	41	.899009	41	217	3	31-52/68
42	.836848	42	.869504	42	222	21	10-40/68
43	.869504	43	.836848	43	227	38	49-28/68
44	.899009	44	.801317	44	232	56	28-16/68
45	.925109	45	.763216	45	238	14	7- 4/68
46	.947582	46	.722869	46	243	31	45-60/68
47	.966236	47	.680621	47	248	49	24-48/68
48	.980913	48	.636832	48	254	7	3-36/68
49	.991487	49	.591875	49	259	24	42-24/68
50	.997867	50	.546134	50	264	42	21-12/68
51	1.000000	51	.500000	51	270	00	00000000
52	.997867	52	.453866	52	275	17	38-56/68
53	.991487	53	.408125	53	280	35	17-44/68
54	.980913	54	.363169	54	285	52	56-32/68
55	.966236	55	.319379	55	291	10	35-20/68
56	.947582	56	.277131	56	296	28	14- 8/68
57	.925109	57	.236784	57	301	45	52-64/68
58	.899009	58	.198683	58	307	3	31-52/68
59	.869504	59	.163152	59	312	21	10-40/68
60	.836848	60	.130496	60	317	38	49-28/68
61	.801317	61	.100991	61	322	56	28-16/68
62	.763216	62	.074891	62	328	14	7- 4/68
63	.722869	63	.052418	63	333	31	45-60/68
64	.680621	64	.033764	64	338	49	24-48/68
65	.636832	65	.019087	65	344	7	3-36/68
66	.591875	66	.008514	66	349	24	42-24/68
67	.546134	67	.002133	67	354	42	21-12/68
68	.500000	68	.000000	68	360	0	0

69 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

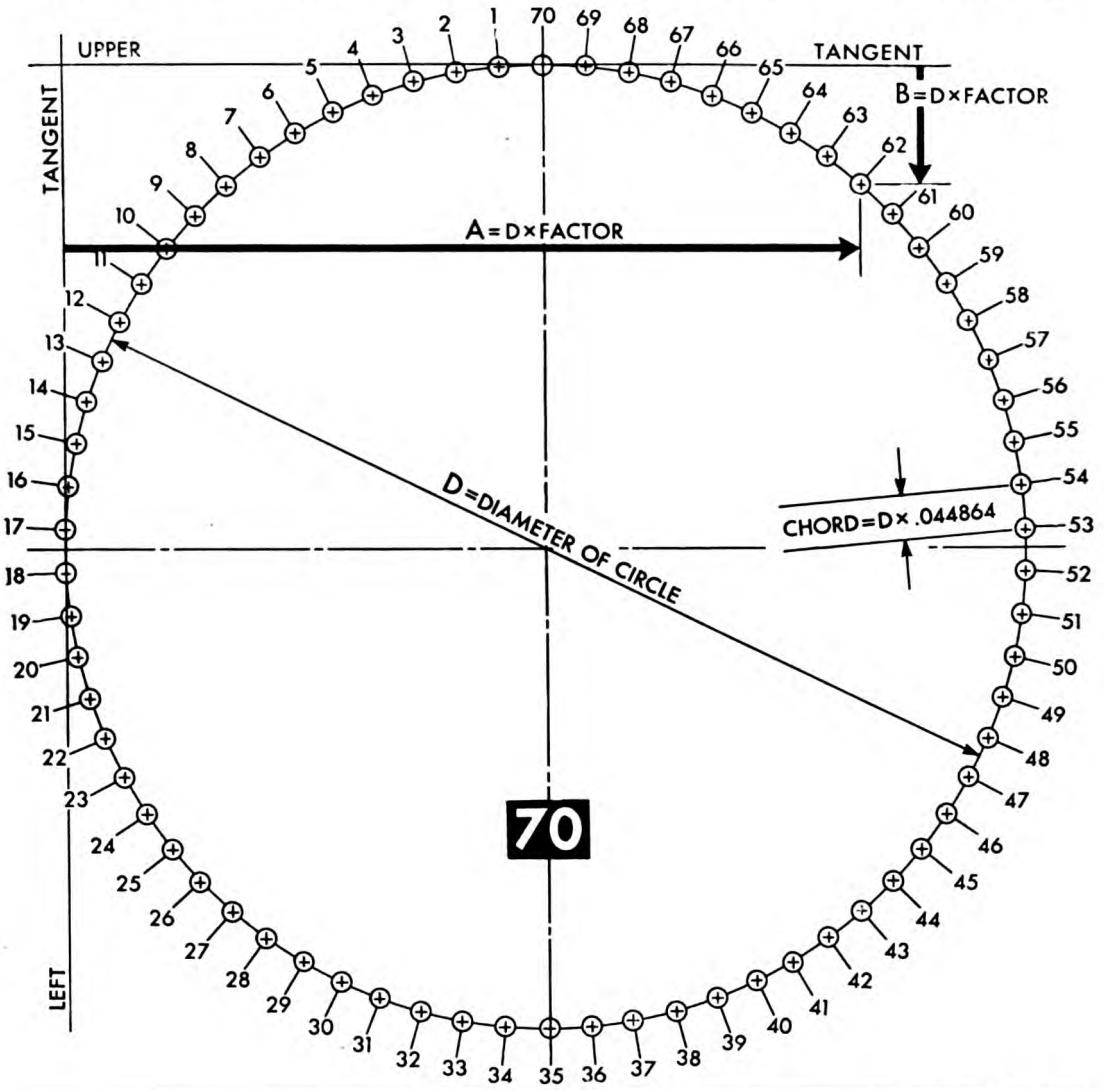


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.454533	1	.002072	1	5	13	2-42/69
2	.409442	2	.008269	2	10	26	5-15/69
3	.365102	3	.018541	3	15	39	7-57/69
4	.321880	4	.032803	4	20	52	10-30/69
5	.280133	5	.050936	5	26	5	13- 3/69
6	.240208	6	.072790	6	31	18	15-45/69
7	.202436	7	.098185	7	36	31	18-18/69
8	.167130	8	.126908	8	41	44	20-60/69
9	.134582	9	.158723	9	46	57	23-33/69
10	.105062	10	.193367	10	52	10	26- 6/69
11	.078815	11	.230551	11	57	23	28-48/69
12	.056057	12	.269968	12	62	36	31-21/69
13	.036979	13	.311290	13	67	49	33-63/69
14	.021737	14	.354177	14	73	2	36-36/69

COORDINATE FACTORS AND ANGLES—69 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.010458	15	.398272	15	78	15	39- 9/69
16	.003236	16	.443210	16	83	28	41-51/69
17	.000130	17	.488618	17	88	41	44-24/69
18	.001166	18	.534121	18	93	54	46-66/69
19	.006335	19	.579341	19	99	7	49-39/69
20	.015595	20	.623904	20	104	20	52-12/69
21	.028870	21	.667440	21	109	33	54-54/69
22	.046048	22	.709588	22	114	46	57-27/69
23	.066987	23	.750000	23	120	00	00000000
24	.091515	24	.788340	24	125	13	2-42/69
25	.119428	25	.824291	25	130	26	5-15/69
26	.150493	26	.857555	26	135	39	7-57/69
27	.184456	27	.887856	27	140	52	10-30/69
28	.221033	28	.914943	28	146	5	13- 3/69
29	.259922	29	.938591	29	151	18	15-45/69
30	.300800	30	.958606	30	156	31	18-18/69
31	.343328	31	.974820	31	161	44	20-60/69
32	.387155	32	.987100	32	166	57	23-33/69
33	.431917	33	.995343	33	172	10	26- 6/69
34	.477243	34	.999482	34	177	23	28-48/69
35	.522757	35	.999482	35	182	36	31-21/69
36	.568083	36	.995343	36	187	49	33-63/69
37	.612845	37	.987100	37	193	2	36-36/69
38	.656672	38	.974820	38	198	15	39- 9/69
39	.699201	39	.958606	39	203	28	41-51/69
40	.740079	40	.938591	40	208	41	44-24/69
41	.778967	41	.914943	41	213	54	46-66/69
42	.815544	42	.887856	42	219	7	49-39/69
43	.849507	43	.857555	43	224	20	52-12/69
44	.880572	44	.824291	44	229	33	54-54/69
45	.908485	45	.788340	45	234	46	57-27/69
46	.933013	46	.750000	46	240	00	00000000
47	.953952	47	.709588	47	245	13	2-42/69
48	.971131	48	.667440	48	250	26	5-15/69
49	.984405	49	.623904	49	255	39	7-57/69
50	.993665	50	.579341	50	260	52	10-30/69
51	.998834	51	.534121	51	266	5	13- 3/69
52	.999870	52	.488618	52	271	18	15-45/69
53	.996764	53	.443210	53	276	31	18-18/69
54	.989542	54	.398272	54	281	44	20-60/69
55	.978263	55	.354177	55	286	57	23-33/69
56	.963021	56	.311290	56	292	10	26- 6/69
57	.943943	57	.269968	57	297	23	28-48/69
58	.921185	58	.230551	58	302	36	31-21/69
59	.894938	59	.193367	59	307	49	33-63/69
60	.865418	60	.158723	60	313	2	36-36/69
61	.832870	61	.126908	61	318	15	39- 9/69
62	.797564	62	.098185	62	323	28	41-51/69
63	.759792	63	.072790	63	328	41	44-24/69
64	.719867	64	.050936	64	333	54	46-66/69
65	.678121	65	.032803	65	339	7	49-39/69
66	.634898	66	.018541	66	344	20	52-12/69
67	.590558	67	.008269	67	349	33	54-54/69
68	.545467	68	.002072	68	354	46	57-27/69
69	.500000	69	.000000	69	360	0	0

70 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

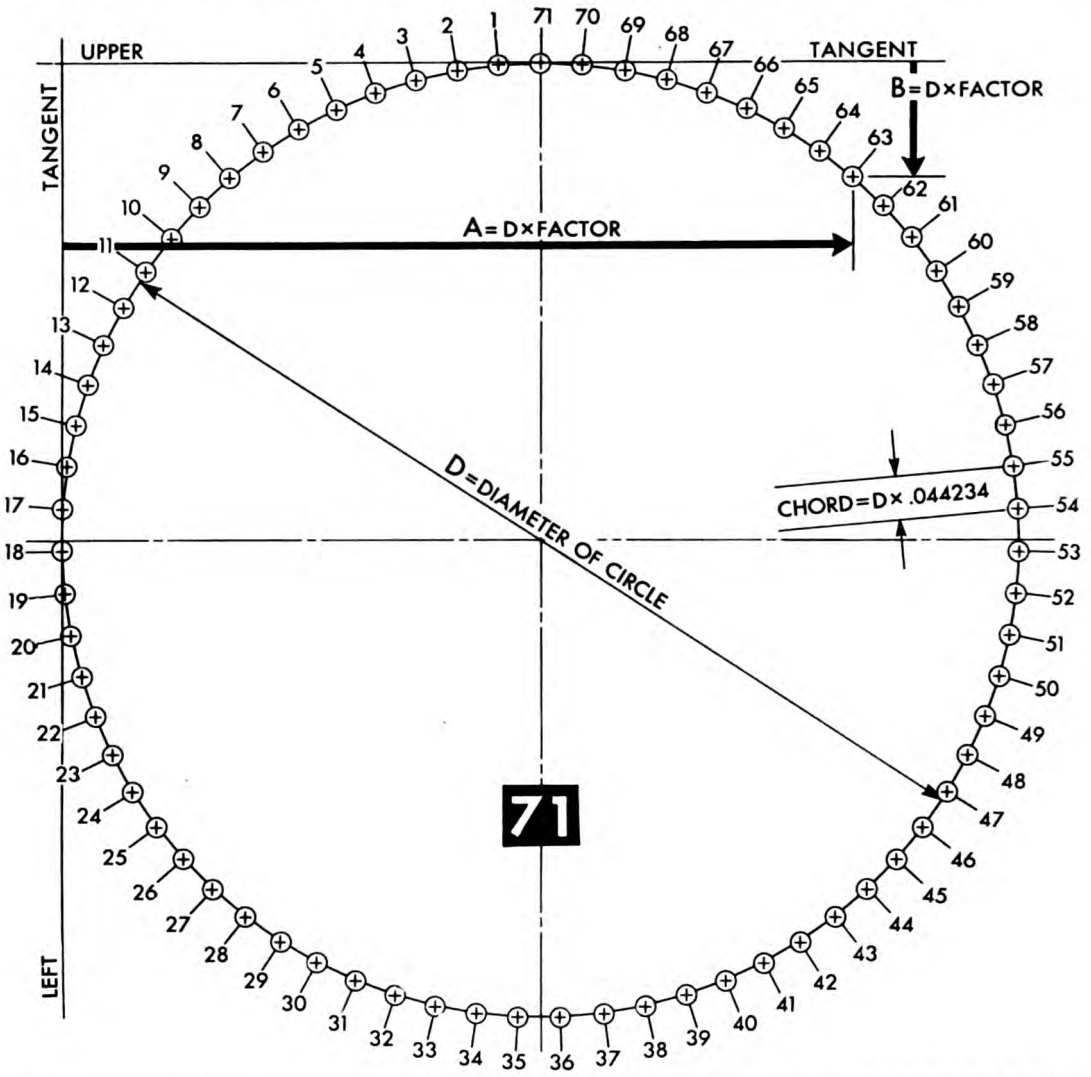


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.455180	1	.002013	1	5	8	34-20/70
2	.410722	2	.008035	2	10	17	8-40/70
3	.366982	3	.018019	3	15	25	42-60/70
4	.324313	4	.031883	4	20	34	17-10/70
5	.283058	5	.049516	5	25	42	51-30/70
6	.243550	6	.070776	6	30	51	25-50/70
7	.206107	7	.095492	7	36	00	00000000
8	.171031	8	.123464	8	41	8	34-20/70
9	.138603	9	.154469	9	46	17	8-40/70
10	.109084	10	.188255	10	51	25	42-60/70
11	.082713	11	.224552	11	56	34	17-10/70
12	.059702	12	.263066	12	61	42	51-30/70
13	.040236	13	.303488	13	66	51	25-50/70
14	.024472	14	.345492	14	72	00	00000000

COORDINATE FACTORS AND ANGLES—70 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
15	.012536	15	.388740	15	77	8	34-20/70
16	.004525	16	.432883	16	82	17	8-40/70
17	.000504	17	.477567	17	87	25	42-60/70
18	.000504	18	.522433	18	92	34	17-10/70
19	.004525	19	.567117	19	97	42	51-30/70
20	.012536	20	.611261	20	102	51	25-50/70
21	.024472	21	.654509	21	108	00	00000000
22	.040236	22	.696513	22	113	8	34-20/70
23	.059702	23	.736934	23	118	17	8-40/70
24	.082713	24	.775449	24	123	25	42-60/70
25	.109084	25	.811745	25	128	34	17-10/70
26	.138603	26	.845531	26	133	42	51-30/70
27	.171031	27	.876536	27	138	51	25-50/70
28	.206107	28	.904509	28	144	00	00000000
29	.243550	29	.929224	29	149	8	34-20/70
30	.283058	30	.950484	30	154	17	8-40/70
31	.324313	31	.968117	31	159	25	42-60/70
32	.366982	32	.981981	32	164	34	17-10/70
33	.410722	33	.991965	33	169	42	51-30/70
34	.455180	34	.997987	34	174	51	25-50/70
35	.500000	35	1.000000	35	180	00	00000000
36	.544820	36	.997987	36	185	8	34-20/70
37	.589278	37	.991965	37	190	17	8-40/70
38	.633018	38	.981981	38	195	25	42-60/70
39	.675687	39	.968117	39	200	34	17-10/70
40	.716942	40	.950484	40	205	42	51-30/70
41	.756450	41	.929224	41	210	51	25-50/70
42	.793893	42	.904509	42	216	00	00000000
43	.828969	43	.876536	43	221	8	34-20/70
44	.861397	44	.845531	44	226	17	8-40/70
45	.890916	45	.811745	45	231	25	42-60/70
46	.917287	46	.775449	46	236	34	17-10/70
47	.940298	47	.736934	47	241	42	51-30/70
48	.959764	48	.696513	48	246	51	25-50/70
49	.975528	49	.654509	49	252	00	00000000
50	.987464	50	.611261	50	257	8	34-20/70
51	.995475	51	.567117	51	262	17	8-40/70
52	.999497	52	.522433	52	267	25	42-60/70
53	.999497	53	.477567	53	272	34	17-10/70
54	.995475	54	.432883	54	277	42	51-30/70
55	.987464	55	.388740	55	282	51	25-50/70
56	.975528	56	.345492	56	288	00	00000000
57	.959764	57	.303488	57	293	8	34-20/70
58	.940298	58	.263066	58	298	17	8-40/70
59	.917287	59	.224552	59	303	25	42-60/70
60	.890916	60	.188255	60	308	34	17-10/70
61	.861397	61	.154469	61	313	42	51-30/70
62	.828969	62	.123464	62	318	51	25-50/70
63	.793893	63	.095492	63	324	00	00000000
64	.756450	64	.070776	64	329	8	34-20/70
65	.716942	65	.049516	65	334	17	8-40/70
66	.675687	66	.031883	66	339	25	42-60/70
67	.633018	67	.018019	67	344	34	17-10/70
68	.589278	68	.008035	68	349	42	51-30/70
69	.544820	69	.002013	69	354	51	25-50/70
70	.500000	70	.000000	70	360	0	0

71 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

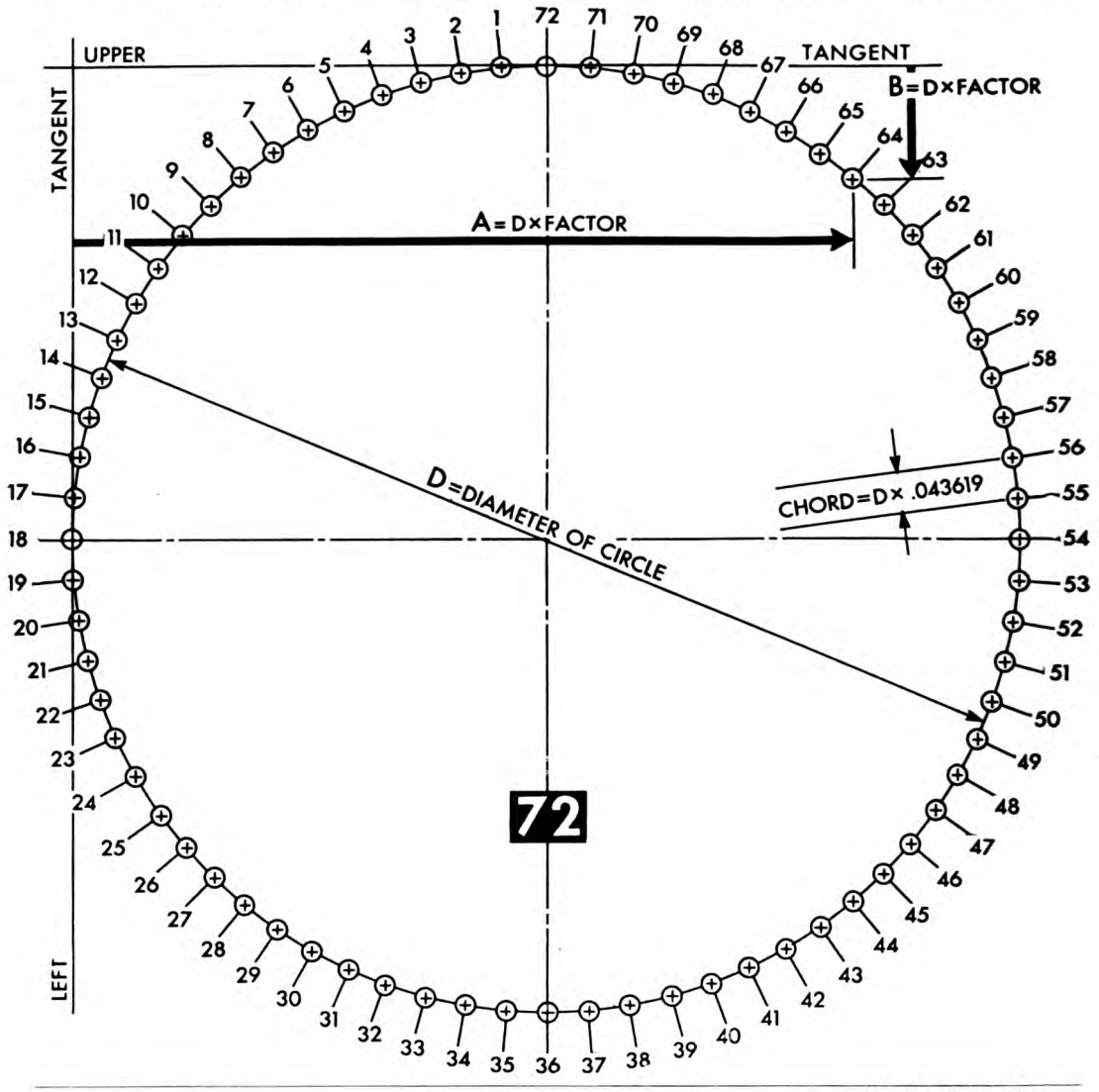


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.455810	1	.001957	1	5	4	13-37/71
2	.411966	2	.007811	2	10	8	27- 3/71
3	.368811	3	.017518	3	15	12	40-40/71
4	.326682	4	.031000	4	20	16	54- 6/71
5	.285910	5	.048153	5	25	21	7-43/71
6	.246814	6	.068843	6	30	25	21- 9/71
7	.209699	7	.092907	7	35	29	34-46/71
8	.174856	8	.120157	8	40	33	48-12/71
9	.142557	9	.150379	9	45	38	1-49/71
10	.113057	10	.183338	10	50	42	15-15/71
11	.086584	11	.218775	11	55	46	28-52/71
12	.063347	12	.256414	12	60	50	42-18/71
13	.043528	13	.295958	13	65	54	55-55/71
14	.027281	14	.337100	14	70	59	9-21/71

COORDINATE FACTORS AND ANGLES—71 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
15	.014733	15	.379516	15	76	3	22-58/71
16	.005984	16	.422876	16	81	7	36-24/71
17	.001101	17	.466839	17	86	11	49-61/71
18	.000122	18	.511061	18	91	16	3-27/71
19	.003056	19	.555196	19	96	20	16-64/71
20	.009879	20	.598901	20	101	24	30-30/71
21	.020538	21	.641831	21	106	28	43-67/71
22	.034949	22	.683651	22	111	32	57-33/71
23	.053000	23	.724033	23	116	37	10-70/71
24	.074549	24	.762663	24	121	41	24-36/71
25	.099428	25	.799236	25	126	45	38- 2/71
26	.127442	26	.833468	26	131	49	51-39/71
27	.158372	27	.865090	27	136	54	5- 5/71
28	.191976	28	.893854	28	141	58	18-42/71
29	.227990	29	.919536	29	147	2	32- 8/71
30	.266133	30	.941935	30	152	6	45-45/71
31	.306106	31	.960874	31	157	10	59-11/71
32	.347597	32	.976207	32	162	15	12-48/71
33	.390281	33	.987813	33	167	19	26-14/71
34	.433823	34	.995601	34	172	23	39-51/71
35	.477883	35	.999511	35	177	27	53-17/71
36	.522117	36	.999511	36	182	32	6-54/71
37	.566177	37	.995601	37	187	36	20-20/71
38	.609719	38	.987813	38	192	40	33-57/71
39	.652403	39	.976207	39	197	44	47-23/71
40	.693894	40	.960874	40	202	49	00-60/71
41	.733868	41	.941935	41	207	53	14-26/71
42	.772010	42	.919536	42	212	57	27-63/71
43	.808024	43	.893854	43	218	1	41-29/71
44	.841628	44	.865090	44	223	5	54-66/71
45	.872558	45	.833468	45	228	10	8-32/71
46	.900572	46	.799236	46	233	14	21-69/71
47	.925451	47	.762663	47	238	18	35-35/71
48	.947000	48	.724033	48	243	22	49- 1/71
49	.965051	49	.683651	49	248	27	2-38/71
50	.979462	50	.641831	50	253	31	16- 4/71
51	.990121	51	.598901	51	258	35	29-41/71
52	.996944	52	.555196	52	263	39	43- 7/71
53	.999878	53	.511061	53	268	43	56-44/71
54	.998899	54	.466839	54	273	48	10-10/71
55	.994016	55	.422876	55	278	52	23-47/71
56	.985267	56	.379516	56	283	56	37-13/71
57	.972719	57	.337100	57	289	00	50-50/71
58	.956472	58	.295958	58	294	5	4-16/71
59	.936653	59	.256414	59	299	9	17-53/71
60	.913416	60	.218775	60	304	13	31-19/71
61	.886944	61	.183338	61	309	17	44-56/71
62	.857443	62	.150379	62	314	21	58-22/71
63	.825144	63	.120157	63	319	26	11-59/71
64	.790301	64	.092907	64	324	30	25-25/71
65	.753187	65	.068843	65	329	34	38-62/71
66	.714090	66	.048153	66	334	38	52-28/71
67	.673318	67	.031000	67	339	43	5-65/71
68	.631190	68	.017518	68	344	47	19-31/71
69	.588034	69	.007811	69	349	51	32-68/71
70	.544190	70	.001957	70	354	55	46-34/71
71	.500000	71	.000000	71	360	0	0

72 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

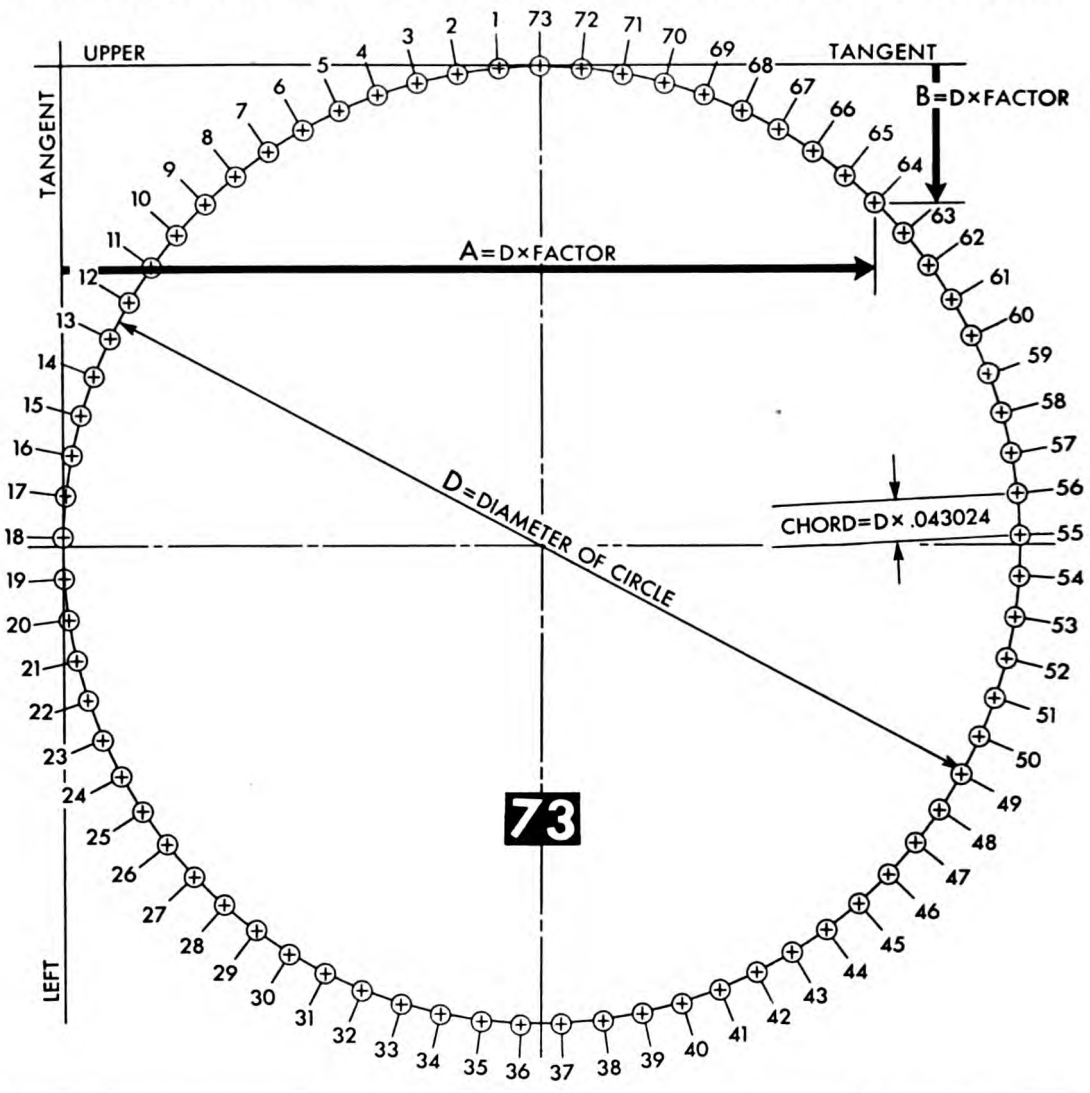


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.456422	1	.001903	1	5	0	0
2	.413176	2	.007596	2	10	0	0
3	.370591	3	.017037	3	15	0	0
4	.328990	4	.030154	4	20	0	0
5	.288691	5	.046846	5	25	0	0
6	.250000	6	.066987	6	30	0	0
7	.213212	7	.090424	7	35	0	0
8	.178606	8	.116978	8	40	0	0
9	.146447	9	.146447	9	45	0	0
10	.116978	10	.178606	10	50	0	0
11	.090424	11	.213212	11	55	0	0
12	.066987	12	.250000	12	60	0	0
13	.046846	13	.288691	13	65	0	0
14	.030154	14	.328990	14	70	0	0

COORDINATE FACTORS AND ANGLES—72 HOLE DIVISION

	FACTOR FOR "A"	FACTOR FOR "B"		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
15	.017037	15	.370591	15	75	0	0
16	.007596	16	.413176	16	80	0	0
17	.001903	17	.456422	17	85	0	0
18	.000000	18	.500000	18	90	0	0
19	.001903	19	.543578	19	95	0	0
20	.007596	20	.586824	20	100	0	0
21	.017037	21	.629410	21	105	0	0
22	.030154	22	.671010	22	110	0	0
23	.046846	23	.711309	23	115	0	0
24	.066987	24	.750000	24	120	0	0
25	.090424	25	.786788	25	125	0	0
26	.116978	26	.821394	26	130	0	0
27	.146447	27	.853553	27	135	0	0
28	.178606	28	.883022	28	140	0	0
29	.213212	29	.909576	29	145	0	0
30	.250000	30	.933013	30	150	0	0
31	.288691	31	.953154	31	155	0	0
32	.328990	32	.969846	32	160	0	0
33	.370591	33	.982963	33	165	0	0
34	.413176	34	.992404	34	170	0	0
35	.456422	35	.998097	35	175	0	0
36	.500000	36	1.000000	36	180	0	0
37	.543578	37	.998097	37	185	0	0
38	.586824	38	.992404	38	190	0	0
39	.629410	39	.982963	39	195	0	0
40	.671010	40	.969846	40	200	0	0
41	.711309	41	.953154	41	205	0	0
42	.750000	42	.933013	42	210	0	0
43	.786788	43	.909576	43	215	0	0
44	.821394	44	.883022	44	220	0	0
45	.853553	45	.853553	45	225	0	0
46	.883022	46	.821394	46	230	0	0
47	.909576	47	.786788	47	235	0	0
48	.933013	48	.750000	48	240	0	0
49	.953154	49	.711309	49	245	0	0
50	.969846	50	.671010	50	250	0	0
51	.982963	51	.629410	51	255	0	0
52	.992404	52	.586824	52	260	0	0
53	.998097	53	.543578	53	265	0	0
54	1.000000	54	.500000	54	270	0	0
55	.998097	55	.456422	55	275	0	0
56	.992404	56	.413176	56	280	0	0
57	.982963	57	.370591	57	285	0	0
58	.969846	58	.328990	58	290	0	0
59	.953154	59	.288691	59	295	0	0
60	.933013	60	.250000	60	300	0	0
61	.909576	61	.213212	61	305	0	0
62	.883022	62	.178606	62	310	0	0
63	.853553	63	.146447	63	315	0	0
64	.821394	64	.116978	64	320	0	0
65	.786788	65	.090424	65	325	0	0
66	.750000	66	.066987	66	330	0	0
67	.711309	67	.046846	67	335	0	0
68	.671010	68	.030154	68	340	0	0
69	.629410	69	.017037	69	345	0	0
70	.586824	70	.007596	70	350	0	0
71	.543578	71	.001903	71	355	0	0
72	.500000	72	.000000	72	360	0	0

73 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

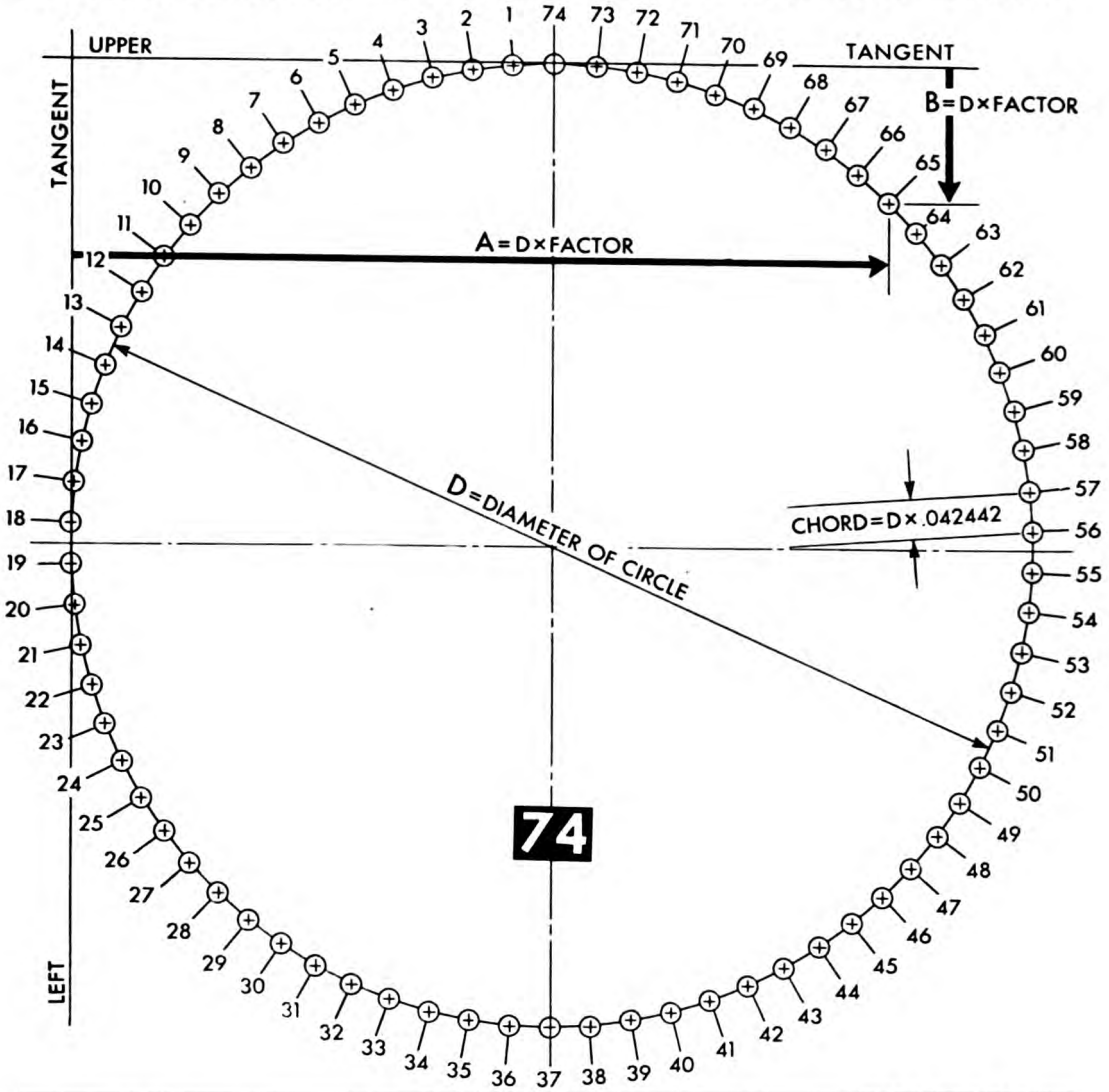


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.457018	1	.001851	1	4	55	53-31/73
2	.414353	2	.007390	2	9	51	46-62/73
3	.372323	3	.016576	3	14	47	40-20/73
4	.331239	4	.029341	4	19	43	33-51/73
5	.291403	5	.045591	5	24	39	27- 9/73
6	.253112	6	.065205	6	29	35	20-40/73
7	.216649	7	.088038	7	34	31	13-71/73
8	.182284	8	.113922	8	39	27	7-29/73
9	.150271	9	.142663	9	44	23	00-60/73
10	.120847	10	.174051	10	49	18	54-18/73
11	.094230	11	.207851	11	54	14	47-49/73
12	.070618	12	.243814	12	59	10	41- 7/73
13	.050185	13	.281674	13	64	6	34-38/73
14	.033081	14	.321151	14	69	2	27-69/73
15	.019435	15	.361952	15	73	58	21-27/73

COORDINATE FACTORS AND ANGLES—73 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
16	.009347	16	.403774	16	78	54	14-58/73
17	.002891	17	.446309	17	83	50	8-16/73
18	.000116	18	.489242	18	88	46	1-47/73
19	.001041	19	.532254	19	93	41	55- 5/73
20	.005661	20	.575028	20	98	37	48-36/73
21	.013941	21	.617246	21	103	33	41-67/73
22	.025819	22	.658595	22	108	29	35-25/73
23	.041208	23	.698771	23	113	25	28-56/73
24	.059994	24	.737476	24	118	21	22-14/73
25	.082037	25	.774421	25	123	17	15-45/73
26	.107175	26	.809336	26	128	13	9- 3/73
27	.135221	27	.841960	27	133	9	2-34/73
28	.165968	28	.872052	28	138	4	55-65/73
29	.199188	29	.899390	29	143	00	49-23/73
30	.234635	30	.923770	30	147	56	42-54/73
31	.272047	31	.945014	31	152	52	36-12/73
32	.311146	32	.962962	32	157	48	29-43/73
33	.351644	33	.977483	33	162	44	23- 1/73
34	.393240	34	.988469	34	167	40	16-32/73
35	.435626	35	.995839	35	172	36	9-63/73
36	.478489	36	.999537	36	177	32	3-21/73
37	.521511	37	.999537	37	182	27	56-52/73
38	.564374	38	.995839	38	187	23	50-10/73
39	.606760	39	.988469	39	192	19	43-41/73
40	.648356	40	.977483	40	197	15	36-72/73
41	.688854	41	.962962	41	202	11	30-30/73
42	.727953	42	.945014	42	207	7	23-61/73
43	.765365	43	.923770	43	212	3	17-19/73
44	.800812	44	.899390	44	216	59	10-50/73
45	.834032	45	.872052	45	221	55	4- 8/73
46	.864779	46	.841960	46	226	50	57-39/73
47	.892825	47	.809336	47	231	46	50-70/73
48	.917963	48	.774421	48	236	42	44-28/73
49	.940006	49	.737476	49	241	38	37-59/73
50	.958792	50	.698771	50	246	34	31-17/73
51	.974181	51	.658595	51	251	30	24-48/73
52	.986059	52	.617246	52	256	26	18- 6/73
53	.994339	53	.575028	53	261	22	11-37/73
54	.998959	54	.532254	54	266	18	4-68/73
55	.999884	55	.489242	55	271	13	58-26/73
56	.997109	56	.446309	56	276	9	51-57/73
57	.990653	57	.403774	57	281	5	45-15/73
58	.980565	58	.361952	58	286	1	38-46/73
59	.966919	59	.321151	59	290	57	32- 4/73
60	.949815	60	.281674	60	295	53	25-35/73
61	.929382	61	.243814	61	300	49	18-66/73
62	.905770	62	.207851	62	305	45	12-24/73
63	.879153	63	.174051	63	310	41	5-55/73
64	.849728	64	.142663	64	315	36	59-13/73
65	.817716	65	.113922	65	320	32	52-44/73
66	.783351	66	.088038	66	325	28	46- 2/73
67	.746888	67	.065205	67	330	24	39-33/73
68	.708597	68	.045591	68	335	20	32-64/73
69	.668761	69	.029341	69	340	16	26-22/73
70	.627677	70	.016576	70	345	12	19-53/73
71	.585647	71	.007390	71	350	8	13-11/73
72	.542982	72	.001851	72	355	4	6-42/73
73	.500000	73	.000000	73	360	0	0

74 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

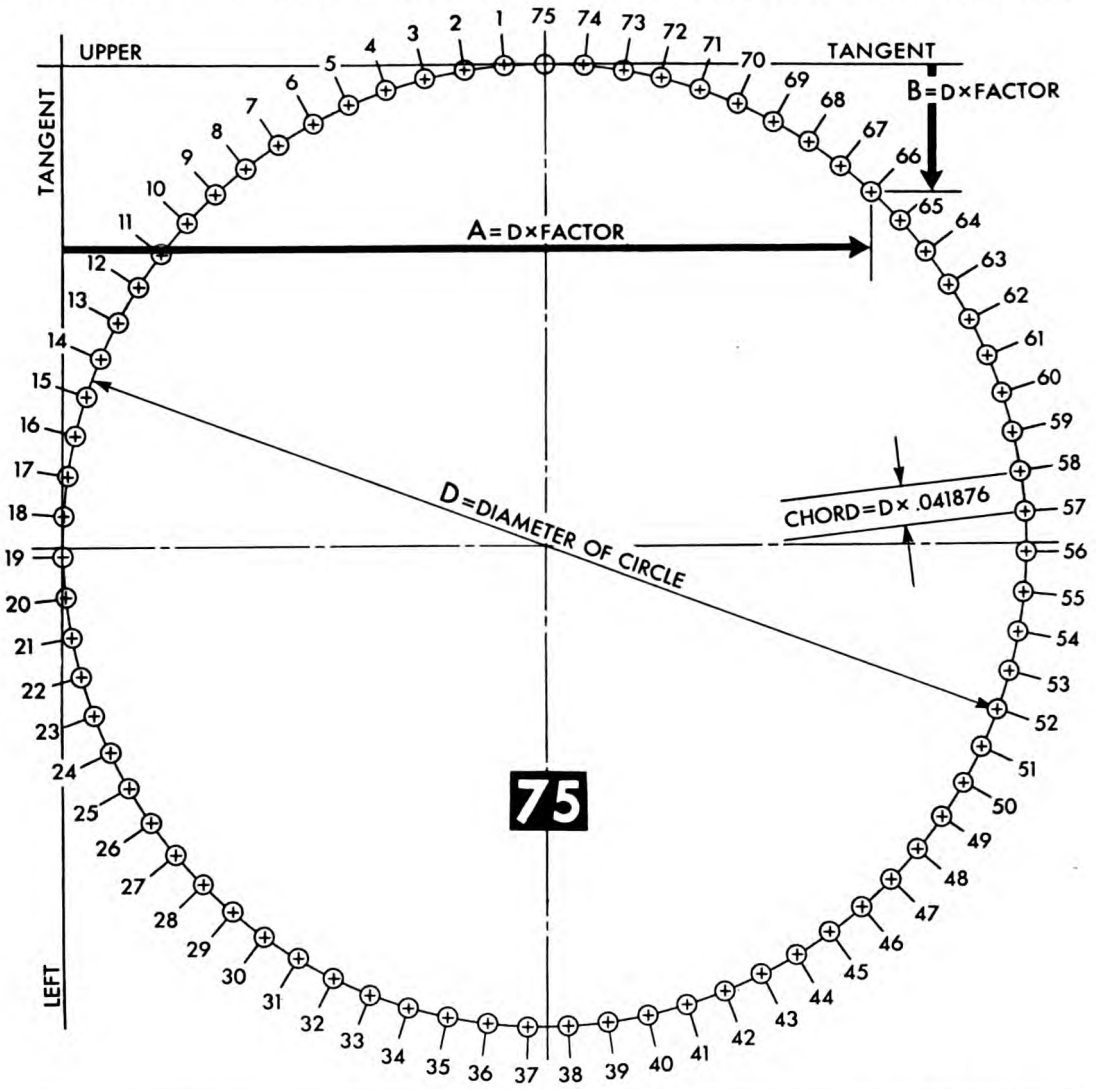


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.457597	1	.001801	1	4	51 53-38/74
2	.415500	2	.007192	2	9	43 47- 2/74
3	.374011	3	.016134	3	14	35 40-40/74
4	.333430	4	.028561	4	19	27 34- 4/74
5	.294049	5	.044386	5	24	19 27-42/74
6	.256153	6	.063493	6	29	11 21- 6/74
7	.220013	7	.085745	7	34	3 14-44/74
8	.185890	8	.110982	8	38	55 8- 8/74
9	.154031	9	.139022	9	43	47 1-46/74
10	.124664	10	.169661	10	48	38 55-10/74
11	.098001	11	.202683	11	53	30 48-48/74
12	.074235	12	.237846	12	58	22 42-12/74
13	.053537	13	.274898	13	63	14 35-50/74
14	.036055	14	.313572	14	68	6 29-14/74
15	.021917	15	.353589	15	72	58 22-52/74

COORDINATE FACTORS AND ANGLES—74 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
16	.011222	16	.394660	16	77	50	16-16/74
17	.004050	17	.436491	17	82	42	9-54/74
18	.000451	18	.478779	18	87	34	3-18/74
19	.000451	19	.521221	19	92	25	56-56/74
20	.004050	20	.563509	20	97	17	50-20/74
21	.011222	21	.605340	21	102	9	43-58/74
22	.021917	22	.646411	22	107	1	37-22/74
23	.036055	23	.686428	23	111	53	30-60/74
24	.053537	24	.725102	24	116	45	24-24/74
25	.074235	25	.762154	25	121	37	17-62/74
26	.098001	26	.797317	26	126	29	11-26/74
27	.124664	27	.830339	27	131	21	4-64/74
28	.154031	28	.860978	28	136	12	58-28/74
29	.185890	29	.889018	29	141	4	51-66/74
30	.220013	30	.914255	30	145	56	45-30/74
31	.256153	31	.936507	31	150	48	38-68/74
32	.294049	32	.955614	32	155	40	32-32/74
33	.333430	33	.971439	33	160	32	25-70/74
34	.374011	34	.983866	34	165	24	19-34/74
35	.415500	35	.992808	35	170	16	12-72/74
36	.457597	36	.998199	36	175	8	6-36/74
37	.500000	37	1.000000	37	180	00	00000000
38	.542403	38	.998199	38	184	51	53-38/74
39	.584500	39	.992808	39	189	43	47- 2/74
40	.625989	40	.983866	40	194	35	40-40/74
41	.666570	41	.971439	41	199	27	34- 4/74
42	.705951	42	.955614	42	204	19	27-42/74
43	.743847	43	.936507	43	209	11	21- 6/74
44	.779987	44	.914255	44	214	3	14-44/74
45	.814110	45	.889018	45	218	55	8- 8/74
46	.845969	46	.860978	46	223	47	1-46/74
47	.875336	47	.830339	47	228	38	55-10/74
48	.901999	48	.797317	48	233	30	48-48/74
49	.925765	49	.762154	49	238	22	42-12/74
50	.946463	50	.725102	50	243	14	35-50/74
51	.963945	51	.686428	51	248	6	29-14/74
52	.978083	52	.646411	52	252	58	22-52/74
53	.988778	53	.605340	53	257	50	16-16/74
54	.995950	54	.563509	54	262	42	9-54/74
55	.999549	55	.521221	55	267	34	3-18/74
56	.999549	56	.478779	56	272	25	56-56/74
57	.995950	57	.436491	57	277	17	50 20/74
58	.988778	58	.394660	58	282	9	43-58/74
59	.978083	59	.353589	59	287	1	37-22/74
60	.963945	60	.313572	60	291	53	30 60/74
61	.946463	61	.274898	61	296	45	24-24/74
62	.925765	62	.237846	62	301	37	17-62/74
63	.901999	63	.202683	63	306	29	11-26/74
64	.875336	64	.169661	64	311	21	4-64/74
65	.845969	65	.139022	65	316	12	58-28/74
66	.814110	66	.110982	66	321	4	51-66/74
67	.779987	67	.085745	67	325	56	45-30/74
68	.743847	68	.063493	68	330	48	38-68/74
69	.705951	69	.044386	69	335	40	32-32/74
70	.666570	70	.028561	70	340	32	25-70/74
71	.625989	71	.016134	71	345	24	19-34/74
72	.584500	72	.007192	72	350	16	12-72/74
73	.542403	73	.001801	73	355	8	6-36/74
74	.500000	74	.000000	74	360	0	0

75 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

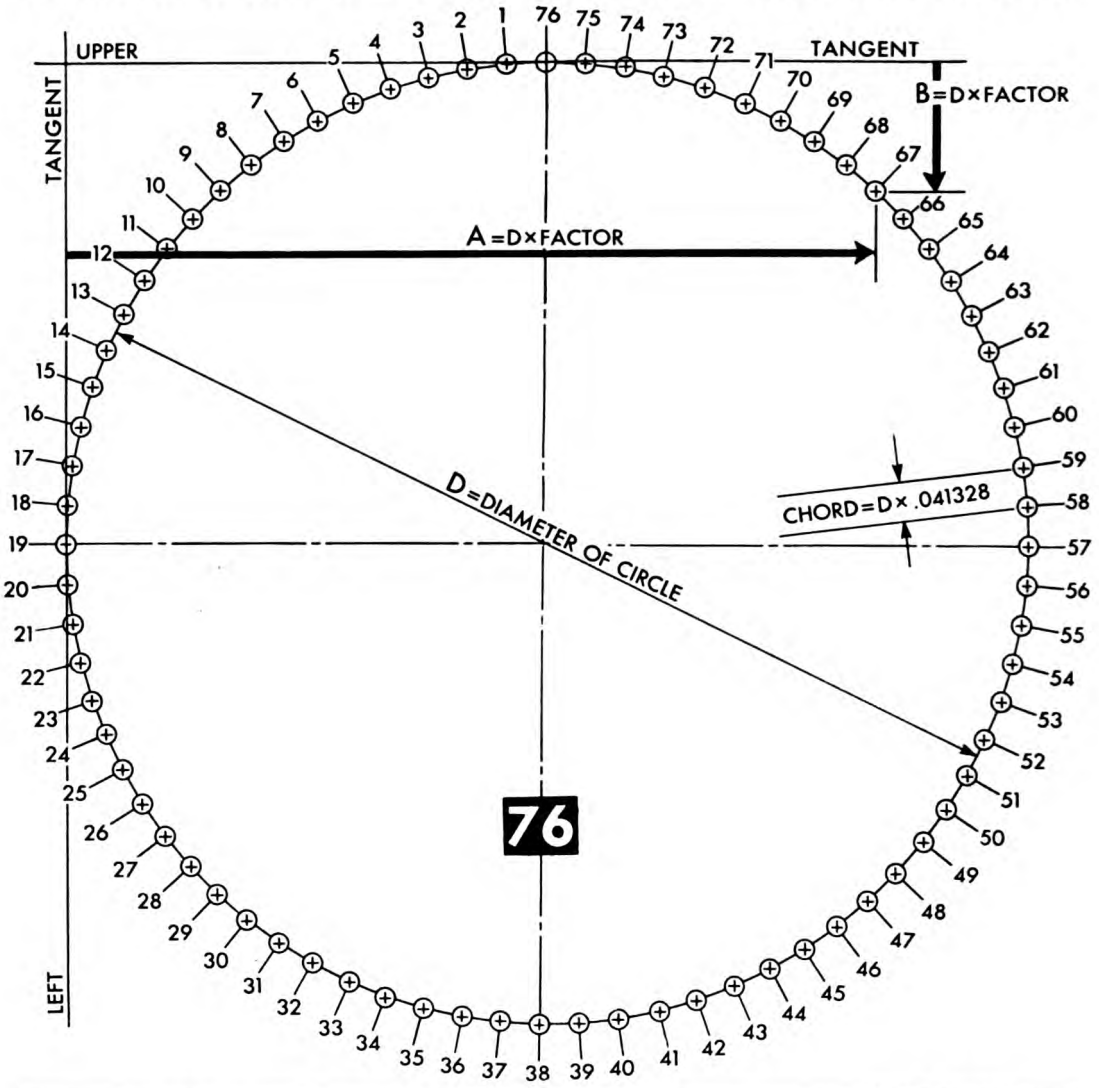


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.458161	1	.001754	1	4	48	0
2	.416616	2	.007002	2	9	36	0
3	.375655	3	.015708	3	14	24	0
4	.335567	4	.027812	4	19	12	0
5	.296632	5	.043227	5	24	00	0
6	.259123	6	.061847	6	28	48	0
7	.223304	7	.083539	7	33	36	0
8	.189426	8	.108153	8	38	24	0
9	.157726	9	.135516	9	43	12	0
10	.128428	10	.165435	10	48	00	0
11	.101735	11	.197700	11	52	48	0
12	.077836	12	.232087	12	57	36	0
13	.056898	13	.268352	13	62	24	0
14	.039068	14	.306242	14	67	12	0
15	.024472	15	.345492	15	72	00	0

COORDINATE FACTORS AND ANGLES—75 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
16	.013211	16	.385825	16	76	48	0
17	.005364	17	.426958	17	81	36	0
18	.000987	18	.468605	18	86	24	0
19	.000110	19	.510471	19	91	12	0
20	.002739	20	.552264	20	96	00	0
21	.008856	21	.593691	21	100	48	0
22	.018419	22	.634460	22	105	36	0
23	.031359	23	.674286	23	110	24	0
24	.047586	24	.712890	24	115	12	0
25	.066987	25	.750000	25	120	00	0
26	.089425	26	.785357	26	124	48	0
27	.114743	27	.818712	27	129	36	0
28	.142764	28	.849832	28	134	24	0
29	.173290	29	.878498	29	139	12	0
30	.206107	30	.904508	30	144	00	0
31	.240987	31	.927682	31	148	48	0
32	.277682	32	.947856	32	153	36	0
33	.315938	33	.964888	33	158	24	0
34	.355484	34	.978660	34	163	12	0
35	.396044	35	.989074	35	168	00	0
36	.437333	36	.996057	36	172	48	0
37	.479062	37	.999561	37	177	36	0
38	.520938	38	.999561	38	182	24	0
39	.562667	39	.996057	39	187	12	0
40	.603956	40	.989074	40	192	00	0
41	.644516	41	.978660	41	196	48	0
42	.684062	42	.964888	42	201	36	0
43	.722318	43	.947856	43	206	24	0
44	.759014	44	.927682	44	211	12	0
45	.793893	45	.904508	45	216	00	0
46	.826710	46	.878498	46	220	48	0
47	.857236	47	.849832	47	225	36	0
48	.885257	48	.818712	48	230	24	0
49	.910575	49	.785357	49	235	12	0
50	.933013	50	.750000	50	240	00	0
51	.952414	51	.712890	51	244	48	0
52	.968641	52	.674286	52	249	36	0
53	.981581	53	.634460	53	254	24	0
54	.991144	54	.593691	54	259	12	0
55	.997261	55	.552264	55	264	00	0
56	.999890	56	.510471	56	268	48	0
57	.999013	57	.468605	57	273	36	0
58	.994636	58	.426958	58	278	24	0
59	.986789	59	.385825	59	283	12	0
60	.975528	60	.345492	60	288	00	0
61	.960932	61	.306242	61	292	48	0
62	.943102	62	.268352	62	297	36	0
63	.922164	63	.232087	63	302	24	0
64	.898265	64	.197700	64	307	12	0
65	.871572	65	.165435	65	312	00	0
66	.842274	66	.135516	66	316	48	0
67	.810574	67	.108153	67	321	36	0
68	.776696	68	.083539	68	326	24	0
69	.740877	69	.061847	69	331	12	0
70	.703368	70	.043227	70	336	00	0
71	.664433	71	.027812	71	340	48	0
72	.624345	72	.015708	72	345	36	0
73	.583384	73	.007002	73	350	24	0
74	.541839	74	.001754	74	355	12	0
75	.500000	75	.000000	75	360	0	0

76 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

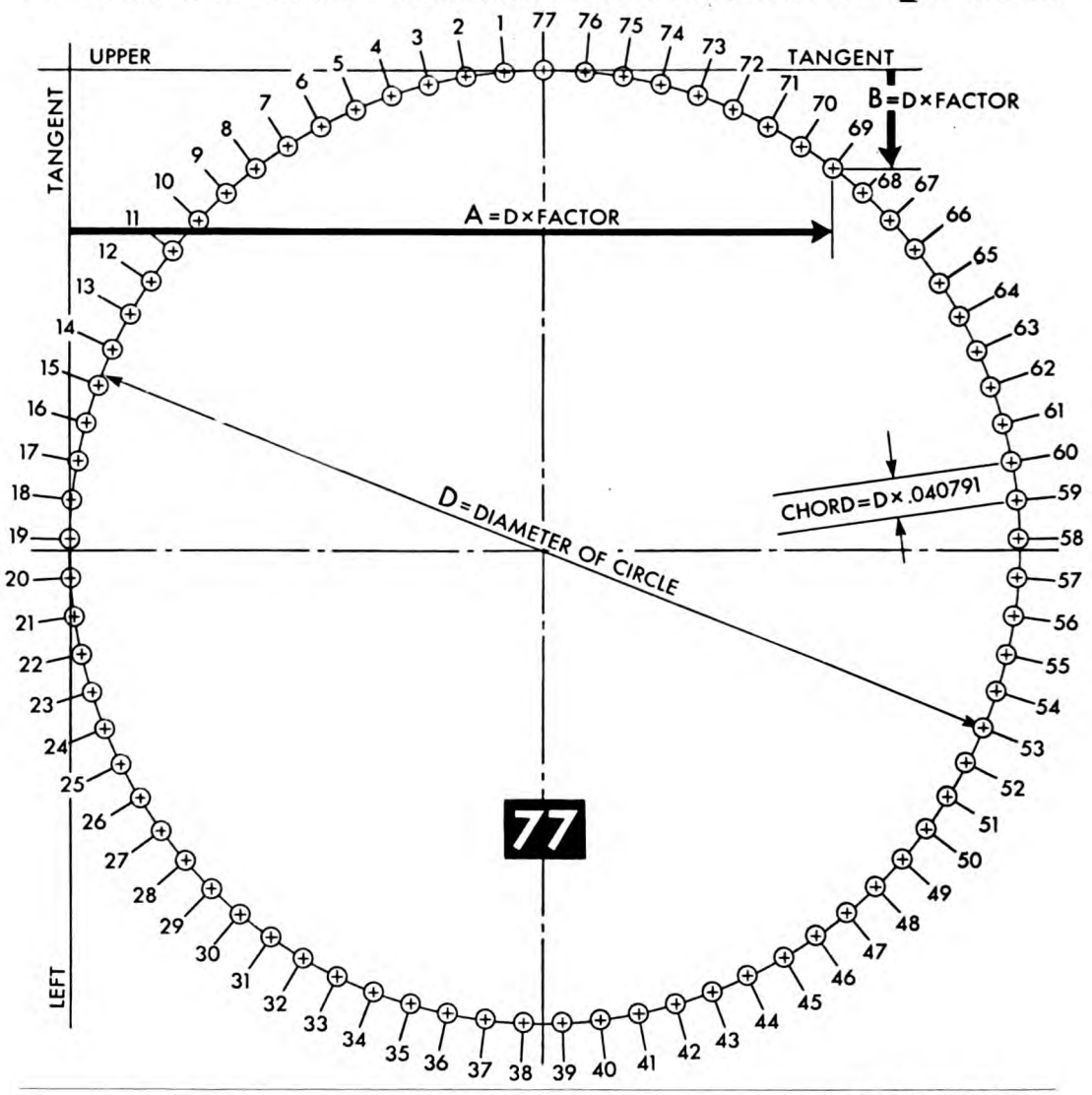


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.458710	1	.001708	1	4	44	12–48/76
2	.417703	2	.006819	2	9	28	25–20/76
3	.377257	3	.015300	3	14	12	37–68/76
4	.337650	4	.027091	4	18	56	50–40/76
5	.299152	5	.042113	5	23	41	3–12/76
6	.262026	6	.060263	6	28	25	15–60/76
7	.226526	7	.081417	7	33	9	28–32/76
8	.192894	8	.105430	8	37	53	41– 4/76
9	.161359	9	.132138	9	42	37	53–52/76
10	.132138	10	.161359	10	47	22	6–24/76
11	.105430	11	.192894	11	52	6	18–72/76
12	.081417	12	.226526	12	56	50	31–44/76
13	.060263	13	.262026	13	61	34	44–16/76
14	.042113	14	.299152	14	66	18	56–64/76
15	.027091	15	.337650	15	71	3	9–36/76

COORDINATE FACTORS AND ANGLES—76 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
16	.015300	16	.377257	16	75	47	22- 8/76
17	.006819	17	.417703	17	80	31	34-56/76
18	.001708	18	.458710	18	85	15	47-28/76
19	.000000	19	.500000	19	90	00	00000000
20	.001708	20	.541290	20	94	44	12-48/76
21	.006819	21	.582297	21	99	28	25-20/76
22	.015300	22	.622743	22	104	12	37-68/76
23	.027091	23	.662350	23	108	56	50-40/76
24	.042113	24	.700848	24	113	41	3-12/76
25	.060263	25	.737974	25	118	25	15-60/76
26	.081417	26	.773474	26	123	9	28-32/76
27	.105430	27	.807106	27	127	53	41- 4/76
28	.132138	28	.838641	28	132	37	53-52/76
29	.161359	29	.867862	29	137	22	6-24/76
30	.192894	30	.894570	30	142	6	18-72/76
31	.226526	31	.918583	31	146	50	31-44/76
32	.262026	32	.939737	32	151	34	44-16/76
33	.299152	33	.957887	33	156	18	56-64/76
34	.337650	34	.972909	34	161	3	9-36/76
35	.377257	35	.984700	35	165	47	22- 8/76
36	.417703	36	.993181	36	170	31	34-56/76
37	.458710	37	.998292	37	175	15	47-28/76
38	.500000	38	1.000000	38	180	00	00000000
39	.541290	39	.998292	39	184	44	12-48/76
40	.582297	40	.993181	40	189	28	25-20/76
41	.622743	41	.984700	41	194	12	37-68/76
42	.662350	42	.972909	42	198	56	50-40/76
43	.700848	43	.957887	43	203	41	3-12/76
44	.737974	44	.939737	44	208	25	15-60/76
45	.773474	45	.918583	45	213	9	28-32/76
46	.807106	46	.894570	46	217	53	41- 4/76
47	.838641	47	.867862	47	222	37	53-52/76
48	.867862	48	.838641	48	227	22	6-24/76
49	.894570	49	.807106	49	232	6	18-72/76
50	.918583	50	.773474	50	236	50	31-44/76
51	.939737	51	.737974	51	241	34	44-16/76
52	.957887	52	.700848	52	246	18	56-64/76
53	.972909	53	.662350	53	251	3	9-36/76
54	.984700	54	.622743	54	255	47	22- 8/76
55	.993181	55	.582297	55	260	31	34-56/76
56	.998292	56	.541290	56	265	15	47-28/76
57	1.000000	57	.500000	57	270	00	00000000
58	.998292	58	.458710	58	274	44	12-48/76
59	.993181	59	.417703	59	279	28	25-20/76
60	.984700	60	.377257	60	284	12	37-68/76
61	.972909	61	.337650	61	288	56	50-40/76
62	.957887	62	.299152	62	293	41	3-12/76
63	.939737	63	.262026	63	298	25	15-60/76
64	.918583	64	.226526	64	303	9	28-32/76
65	.894570	65	.192894	65	307	53	41- 4/76
66	.867862	66	.161359	66	312	37	53-52/76
67	.838641	67	.132138	67	317	22	6-24/76
68	.807106	68	.105430	68	322	6	18-72/76
69	.773474	69	.081417	69	326	50	31-44/76
70	.737974	70	.060263	70	331	34	44-16/76
71	.700848	71	.042113	71	336	18	56-64/76
72	.662350	72	.027091	72	341	3	9-36/76
73	.622743	73	.015300	73	345	47	22- 8/76
74	.582297	74	.006819	74	350	31	34-56/76
75	.541290	75	.001708	75	355	15	47-28/76
76	.500000	76	.000000	76	360	0	0

77 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

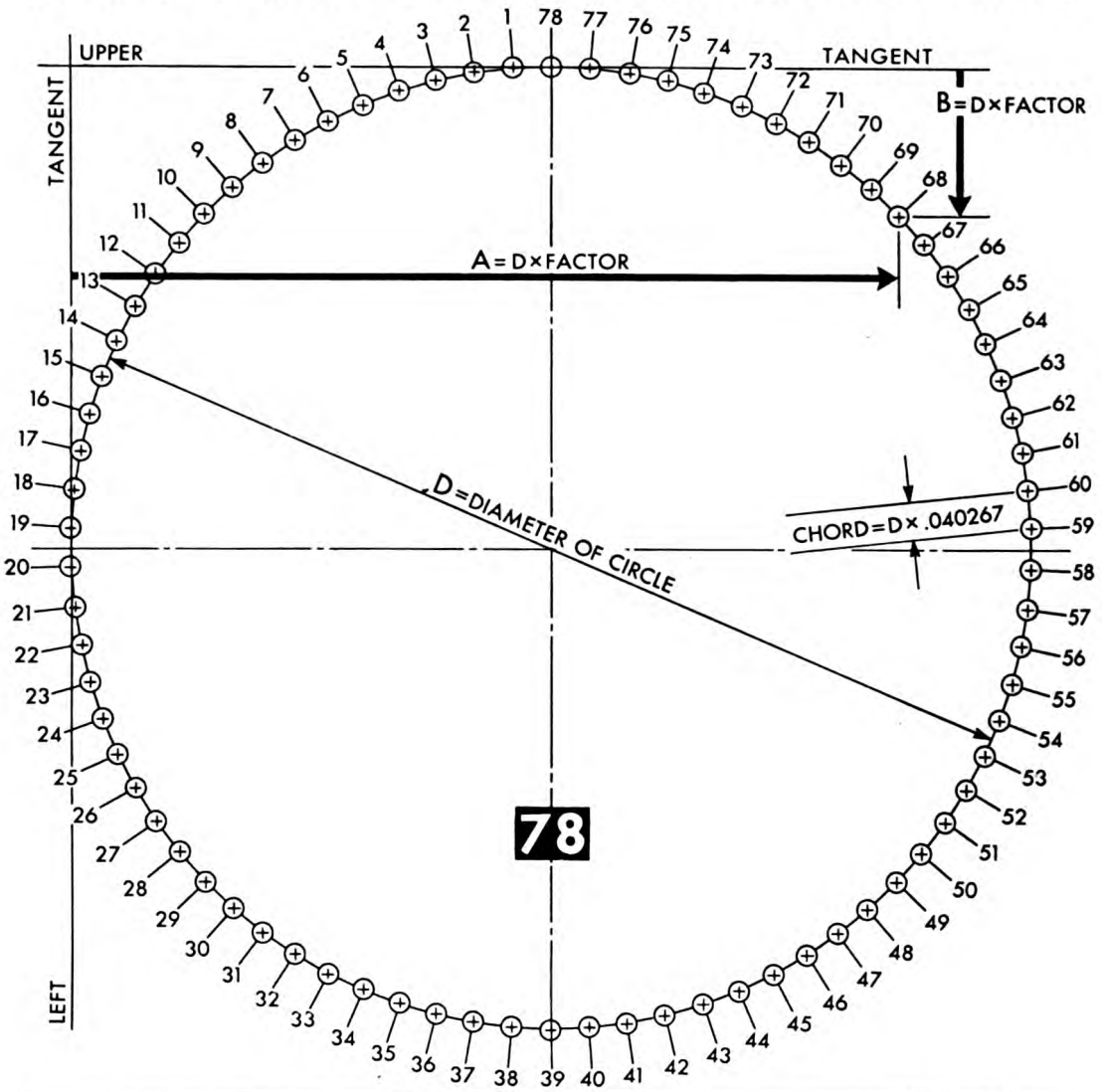


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.459245	1	.001664	1	4	40	31-13/77
2	.418762	2	.006644	2	9	21	2-26/77
3	.378819	3	.014907	3	14	1	33-39/77
4	.339683	4	.026399	4	18	42	4-52/77
5	.301613	5	.041042	5	23	22	35-65/77
6	.264864	6	.058739	6	28	3	7- 1/77
7	.229680	7	.079373	7	32	43	38-14/77
8	.196294	8	.102806	8	37	24	9-27/77
9	.164930	9	.128883	9	42	4	40-40/77
10	.135795	10	.157429	10	46	45	11-53/77
11	.109084	11	.188255	11	51	25	42-66/77
12	.084975	12	.221156	12	56	6	14- 2/77
13	.063627	13	.255912	13	60	46	45-15/77
14	.045184	14	.292293	14	65	27	16-28/77
15	.029767	15	.330055	15	70	7	47-41/77
16	.017480	16	.368949	16	74	48	18-54/77

COORDINATE FACTORS AND ANGLES—77 HOLE DIVISION

	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	➡		⬇		DEG.	MIN.	SEC.
17	.008404	17	.408715	17	79	28	49-67/77
18	.002599	18	.449089	18	84	9	21- 3/77
19	.000104	19	.489801	19	88	49	52-16/77
20	.000936	20	.530581	20	93	30	23-29/77
21	.005089	21	.571157	21	98	10	54-42/77
22	.012536	22	.611260	22	102	51	25-55/77
23	.023227	23	.650623	23	107	31	56-68/77
24	.037090	24	.688983	24	112	12	28- 4/77
25	.054035	25	.726086	25	116	52	59-17/77
26	.073947	26	.761685	26	121	33	30-30/77
27	.096694	27	.795541	27	126	14	1-43/77
28	.122125	28	.827430	28	130	54	32-56/77
29	.150071	29	.857141	29	135	35	3-69/77
30	.180346	30	.884475	30	140	15	35- 5/77
31	.212748	31	.909251	31	144	56	6-18/77
32	.247061	32	.931303	32	149	36	37-31/77
33	.283058	33	.950484	33	154	17	8-44/77
34	.320499	34	.966668	34	158	57	39-57/77
35	.359134	35	.979746	35	163	38	10-70/77
36	.398706	36	.989632	36	168	18	42- 6/77
37	.438953	37	.996259	37	172	59	13-19/77
38	.479606	38	.999584	38	177	39	44-32/77
39	.520395	39	.999584	39	182	20	15-45/77
40	.561047	40	.996259	40	187	00	46-58/77
41	.601294	41	.989632	41	191	41	17-71/77
42	.640866	42	.979746	42	196	21	49- 7/77
43	.679501	43	.966668	43	201	2	20-20/77
44	.716942	44	.950484	44	205	42	51-33/77
45	.752939	45	.931303	45	210	23	22-46/77
46	.787252	46	.909251	46	215	3	53-59/77
47	.819654	47	.884475	47	219	44	24-72/77
48	.849929	48	.857141	48	224	24	56- 8/77
49	.877874	49	.827430	49	229	5	27-21/77
50	.903306	50	.795541	50	233	45	58-34/77
51	.926053	51	.761685	51	238	26	29-47/77
52	.945965	52	.726086	52	243	7	00-60/77
53	.962910	53	.688983	53	247	47	31-73/77
54	.976773	54	.650623	54	252	28	3- 9/77
55	.987464	55	.611260	55	257	8	34-22/77
56	.994911	56	.571157	56	261	49	5-35/77
57	.999064	57	.530581	57	266	29	36-48/77
58	.999896	58	.489801	58	271	10	7-61/77
59	.997401	59	.449089	59	275	50	38-74/77
60	.991596	60	.408715	60	280	31	10-10/77
61	.982520	61	.368949	61	285	11	41-23/77
62	.970233	62	.330055	62	289	52	12-36/77
63	.954816	63	.292293	63	294	32	43-49/77
64	.936373	64	.255912	64	299	13	14-62/77
65	.915025	65	.221156	65	303	53	45-75/77
66	.890916	66	.188255	66	308	34	17-11/77
67	.864205	67	.157429	67	313	14	48-24/77
68	.835070	68	.128883	68	317	55	19-37/77
69	.803706	69	.102806	69	322	35	50-50/77
70	.770320	70	.079373	70	327	16	21-63/77
71	.735136	71	.058739	71	331	56	52-76/77
72	.698387	72	.041042	72	336	37	24-12/77
73	.660317	73	.026399	73	341	17	55-25/77
74	.621181	74	.014907	74	345	58	26-38/77
75	.581238	75	.006644	75	350	38	57-51/77
76	.540755	76	.001664	76	355	19	28-64/77
77	.500000	77	.000000	77	360	0	0

78 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

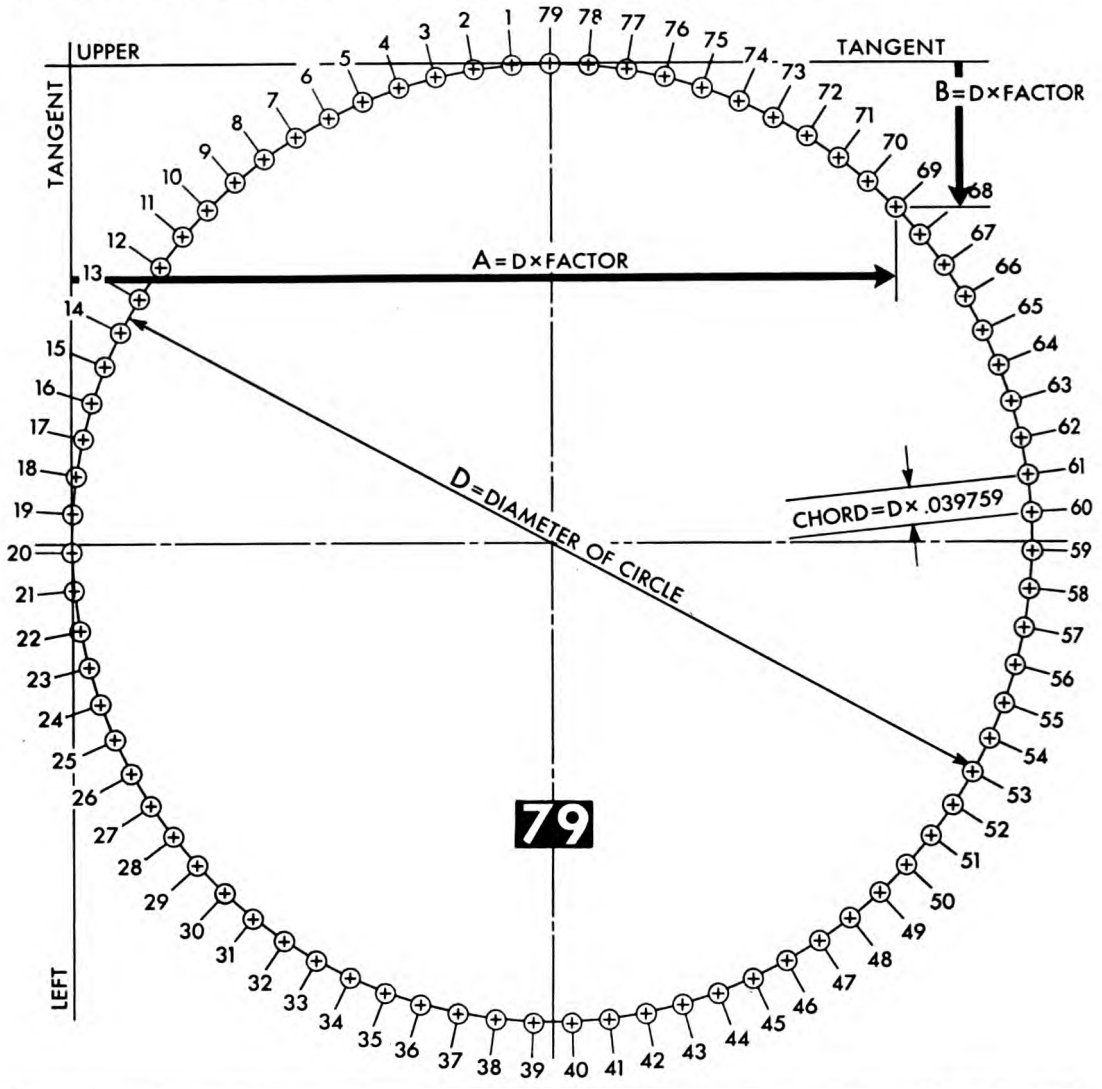


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	➡		⬇		DEG.	MIN.	SEC.
1	.459767	1	.001621	1	4	36	55–30/78
2	.419794	2	.006475	2	9	13	50–60/78
3	.380342	3	.014529	3	13	50	46–12/78
4	.341666	4	.025732	4	18	27	41–42/78
5	.304017	5	.040010	5	23	4	36–72/78
6	.267638	6	.057272	6	27	41	32–24/78
7	.232767	7	.077405	7	32	18	27–54/78
8	.199629	8	.100279	8	36	55	23– 6/78
9	.168439	9	.125745	9	41	32	18–36/78
10	.139399	10	.153638	10	46	9	13–66/78
11	.112698	11	.183777	11	50	46	9–18/78
12	.088508	12	.215968	12	55	23	4–48/78
13	.066987	13	.250000	13	60	00	00000000
14	.048275	14	.285654	14	64	36	55–30/78
15	.032492	15	.322698	15	69	13	50–60/78
16	.019741	16	.360891	16	73	50	46–12/78

COORDINATE FACTORS AND ANGLES—78 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
17	.010105	17	.399987	17	78	27	41-42/78
18	.003646	18	.439732	18	83	4	36-72/78
19	.000406	19	.479867	19	87	41	32-24/78
20	.000406	20	.520133	20	92	18	27-54/78
21	.003646	21	.560268	21	96	55	23- 6/78
22	.010105	22	.600013	22	101	32	18-36/78
23	.019741	23	.639109	23	106	9	13-66/78
24	.032492	24	.677302	24	110	46	9-18/78
25	.048275	25	.714346	25	115	23	4-48/78
26	.066987	26	.750000	26	120	00	00000000
27	.088508	27	.784032	27	124	36	55-30/78
28	.112698	28	.816223	28	129	13	50-60/78
29	.139399	29	.846362	29	133	50	46-12/78
30	.168439	30	.874255	30	138	27	41-42/78
31	.199629	31	.899721	31	143	4	36-72/78
32	.232767	32	.922595	32	147	41	32-24/78
33	.267638	33	.942728	33	152	18	27-54/78
34	.304017	34	.959990	34	156	55	23- 6/78
35	.341666	35	.974268	35	161	32	18-36/78
36	.380342	36	.985471	36	166	9	13-66/78
37	.419794	37	.993525	37	170	46	9-18/78
38	.459767	38	.998379	38	175	23	4-48/78
39	.500000	39	1.000000	39	180	00	00000000
40	.540233	40	.998379	40	184	36	55-30/78
41	.580206	41	.993525	41	189	13	50-60/78
42	.619658	42	.985471	42	193	50	46-12/78
43	.658334	43	.974268	43	198	27	41-42/78
44	.695983	44	.959990	44	203	4	36-72/78
45	.732362	45	.942728	45	207	41	32-24/78
46	.767233	46	.922595	46	212	18	27-54/78
47	.800371	47	.899721	47	216	55	23- 6/78
48	.831561	48	.874255	48	221	32	18-36/78
49	.860601	49	.846362	49	226	9	13-66/78
50	.887302	50	.816223	50	230	46	9-18/78
51	.911492	51	.784032	51	235	23	4-48/78
52	.933013	52	.750000	52	240	00	00000000
53	.951725	53	.714346	53	244	36	55-30/78
54	.967508	54	.677302	54	249	13	50-60/78
55	.980259	55	.639109	55	253	50	46-12/78
56	.989895	56	.600013	56	258	27	41-42/78
57	.996354	57	.560268	57	263	4	36-72/78
58	.999595	58	.520133	58	267	41	32-24/78
59	.999595	59	.479867	59	272	18	27-54/78
60	.996354	60	.439732	60	276	55	23- 6/78
61	.989895	61	.399987	61	281	32	18-36/78
62	.980259	62	.360891	62	286	9	13-66/78
63	.967508	63	.322698	63	290	46	9-18/78
64	.951725	64	.285654	64	295	23	4-48/78
65	.933013	65	.250000	65	300	00	00000000
66	.911492	66	.215968	66	304	36	55-30/78
67	.887302	67	.183777	67	309	13	50-60/78
68	.860601	68	.153638	68	313	50	46-12/78
69	.831561	69	.125745	69	318	27	41-42/78
70	.800371	70	.100279	70	323	4	36-72/78
71	.767233	71	.077405	71	327	41	32-24/78
72	.732362	72	.057272	72	332	18	27-54/78
73	.695983	73	.040010	73	336	55	23- 6/78
74	.658334	74	.025732	74	341	32	18-36/78
75	.619658	75	.014529	75	346	9	13-66/78
76	.580206	76	.006475	76	350	46	9-18/78
77	.540233	77	.001621	77	355	23	4-48/78
78	.500000	78	.000000	78	360	0	0

79 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

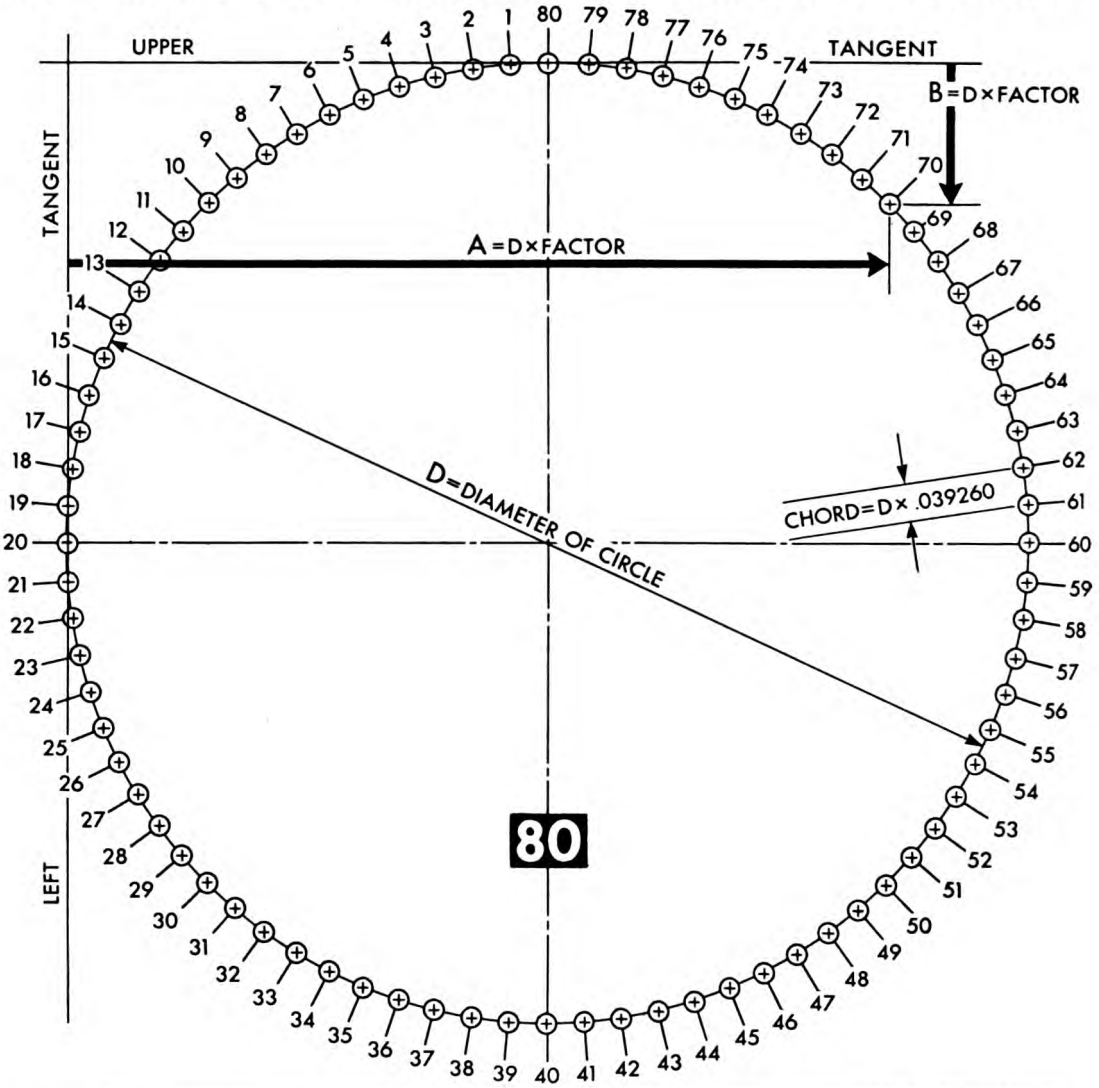


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.460275	1	.001581	1	4	33	25- 5/79
2	.420801	2	.006312	2	9	6	50-10/79
3	.381828	3	.014165	3	13	40	15-15/79
4	.343602	4	.025090	4	18	13	40-20/79
5	.306364	5	.039017	5	22	47	5-25/79
6	.270351	6	.055858	6	27	20	30-30/79
7	.235790	7	.075508	7	31	53	55-35/79
8	.202899	8	.097842	8	36	27	20-40/79
9	.171887	9	.122718	9	41	00	45-45/79
10	.142949	10	.149979	10	45	34	10-50/79
11	.116269	11	.179453	11	50	7	35-55/79
12	.092014	12	.210954	12	54	41	00-60/79
13	.070339	13	.244282	13	59	14	25-65/79
14	.051381	14	.279227	14	63	47	50-70/79
15	.035258	15	.315568	15	68	21	15-75/79
16	.022074	16	.353075	16	72	54	41- 1/79

COORDINATE FACTORS AND ANGLES—79 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
17	.011912	17	.391511	17	77	28	6- 6/79
18	.004835	18	.430632	18	82	1	31-11/79
19	.000889	19	.470192	19	86	34	56-16/79
20	.000099	20	.509941	20	91	8	21-21/79
21	.002469	21	.549627	21	95	41	46-26/79
22	.007985	22	.588999	22	100	15	11-31/79
23	.016611	23	.627808	23	104	48	36-36/79
24	.028293	24	.665810	24	109	22	1-41/79
25	.042958	25	.702763	25	113	55	26-46/79
26	.060512	26	.738434	26	118	28	51-51/79
27	.080845	27	.772597	27	123	2	16-56/79
28	.103828	28	.805038	28	127	35	41-61/79
29	.129316	29	.835549	29	132	9	6-66/79
30	.157147	30	.863939	30	136	42	31-71/79
31	.187146	31	.890029	31	141	15	56-76/79
32	.219123	32	.913652	32	145	49	22- 2/79
33	.252875	33	.934660	33	150	22	47- 7/79
34	.288190	34	.952920	34	154	56	12-12/79
35	.324845	35	.968317	35	159	29	37-17/79
36	.362606	36	.980752	36	164	3	2-22/79
37	.401236	37	.990149	37	168	36	27-27/79
38	.440491	38	.996446	38	173	9	52-32/79
39	.480122	39	.999605	39	177	43	17-37/79
40	.519878	40	.999605	40	182	16	42-42/79
41	.559509	41	.996446	41	186	50	7-47/79
42	.598764	42	.990149	42	191	23	32-52/79
43	.637394	43	.980752	43	195	56	57-57/79
44	.675155	44	.968317	44	200	30	22-62/79
45	.711810	45	.952920	45	205	3	47-67/79
46	.747125	46	.934660	46	209	37	12-72/79
47	.780877	47	.913652	47	214	10	37-77/79
48	.812854	48	.890029	48	218	44	3- 3/79
49	.842853	49	.863939	49	223	17	28- 8/79
50	.870684	50	.835549	50	227	50	53-13/79
51	.896172	51	.805038	51	232	24	18-18/79
52	.919155	52	.772597	52	236	57	43-23/79
53	.939488	53	.738434	53	241	31	8-28/79
54	.957042	54	.702763	54	246	4	33-33/79
55	.971707	55	.665810	55	250	37	58-38/79
56	.983389	56	.627808	56	255	11	23-43/79
57	.992015	57	.588999	57	259	44	48-48/79
58	.997531	58	.549627	58	264	18	13-53/79
59	.999901	59	.509941	59	268	51	38-58/79
60	.999111	60	.470192	60	273	25	3-63/79
61	.995165	61	.430632	61	277	58	28-68/79
62	.988088	62	.391511	62	282	31	53-73/79
63	.977926	63	.353075	63	287	5	18-78/79
64	.964742	64	.315568	64	291	38	44- 4/79
65	.948619	65	.279227	65	296	12	9- 9/79
66	.929661	66	.244282	66	300	45	34-14/79
67	.907986	67	.210954	67	305	18	59-19/79
68	.883731	68	.179453	68	309	52	24-24/79
69	.857051	69	.149979	69	314	25	49-29/79
70	.828113	70	.122718	70	318	59	14-34/79
71	.797101	71	.097842	71	323	32	39-39/79
72	.764210	72	.075508	72	328	6	4-44/79
73	.729649	73	.055858	73	332	39	29-49/79
74	.693636	74	.039017	74	337	12	54-54/79
75	.656398	75	.025090	75	341	46	19-59/79
76	.618172	76	.014165	76	346	19	44-64/79
77	.579199	77	.006312	77	350	53	9-69/79
78	.539725	78	.001581	78	355	26	34-74/79
79	.500000	79	.000000	79	360	0	0

80 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

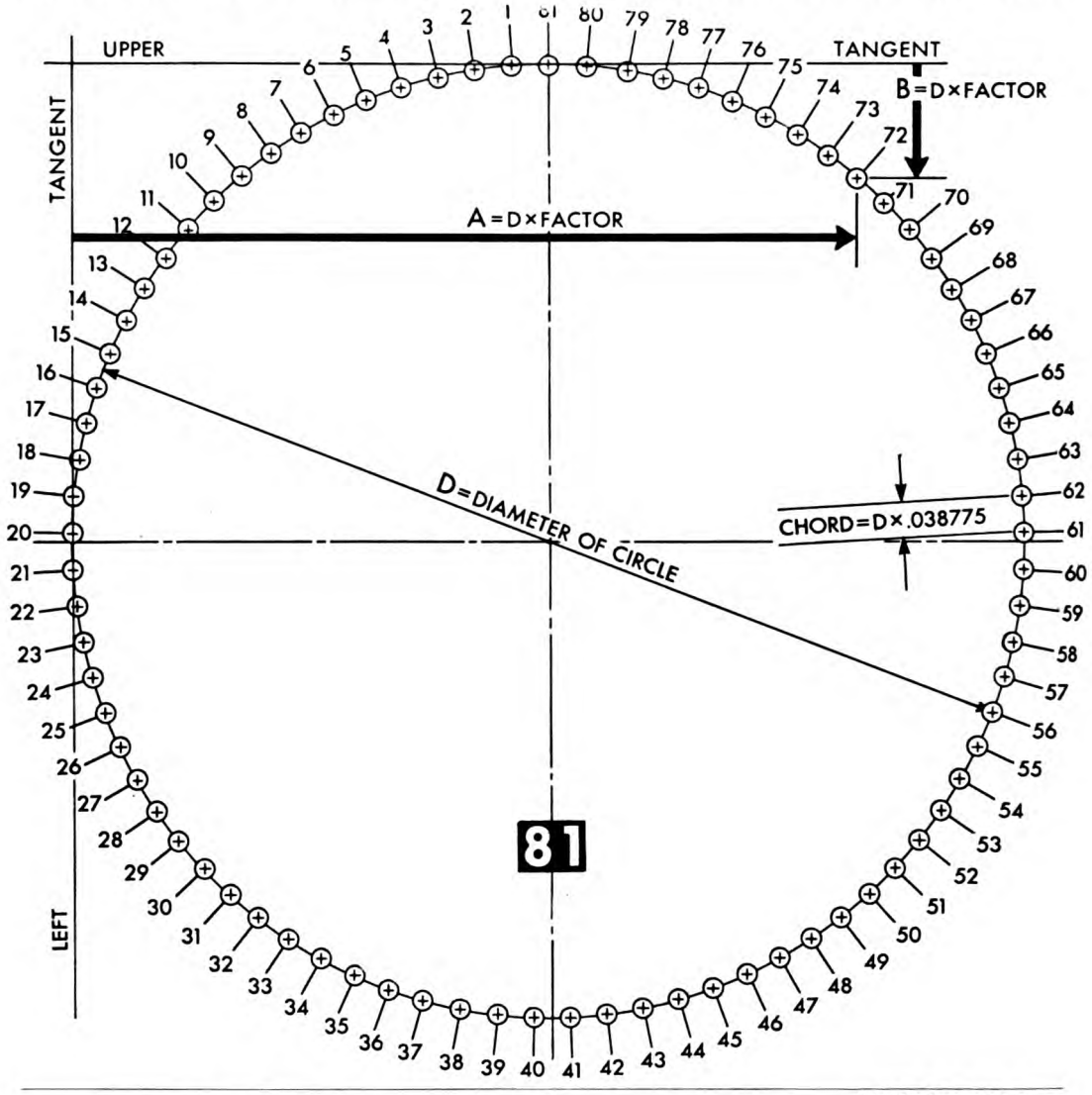


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.460770	1	.001541	1	4	30	0
2	.421783	2	.006156	2	9	00	0
3	.383277	3	.013815	3	13	30	0
4	.345492	4	.024472	4	18	00	0
5	.308658	5	.038060	5	22	30	0
6	.273005	6	.054497	6	27	00	0
7	.238751	7	.073680	7	31	30	0
8	.206107	8	.095492	8	36	00	0
9	.175276	9	.119797	9	40	30	0
10	.146447	10	.146447	10	45	00	0
11	.119797	11	.175276	11	49	30	0
12	.095492	12	.206107	12	54	00	0
13	.073680	13	.238751	13	58	30	0
14	.054497	14	.273005	14	63	00	0
15	.038060	15	.308658	15	67	30	0
16	.024472	16	.345492	16	72	00	0
17	.013815	17	.383277	17	76	30	0

COORDINATE FACTORS AND ANGLES—80 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
18	.006156	18	.421783	18	81	00	0
19	.001541	19	.460770	19	85	30	0
20	.000000	20	.500000	20	90	00	0
21	.001541	21	.539230	21	94	30	0
22	.006156	22	.578217	22	99	00	0
23	.013815	23	.616723	23	103	30	0
24	.024472	24	.654508	24	108	00	0
25	.038060	25	.691342	25	112	30	0
26	.054497	26	.726995	26	117	00	0
27	.073680	27	.761249	27	121	30	0
28	.095492	28	.793893	28	126	00	0
29	.119797	29	.824724	29	130	30	0
30	.146447	30	.853553	30	135	00	0
31	.175276	31	.880203	31	139	30	0
32	.206107	32	.904508	32	144	00	0
33	.238751	33	.926320	33	148	30	0
34	.273005	34	.945503	34	153	00	0
35	.308658	35	.961940	35	157	30	0
36	.345492	36	.975528	36	162	00	0
37	.383277	37	.986185	37	166	30	0
38	.421783	38	.993844	38	171	00	0
39	.460770	39	.998459	39	175	30	0
40	.500000	40	1.000000	40	180	00	0
41	.539230	41	.998459	41	184	30	0
42	.578217	42	.993844	42	189	00	0
43	.616723	43	.986185	43	193	30	0
44	.654508	44	.975528	44	198	00	0
45	.691342	45	.961940	45	202	30	0
46	.726995	46	.945503	46	207	00	0
47	.761249	47	.926320	47	211	30	0
48	.793893	48	.904508	48	216	00	0
49	.824724	49	.880203	49	220	30	0
50	.853553	50	.853553	50	225	00	0
51	.880203	51	.824724	51	229	30	0
52	.904508	52	.793893	52	234	00	0
53	.926320	53	.761249	53	238	30	0
54	.945503	54	.726995	54	243	00	0
55	.961940	55	.691342	55	247	30	0
56	.975528	56	.654508	56	252	00	0
57	.986185	57	.616723	57	256	30	0
58	.993844	58	.578217	58	261	00	0
59	.998459	59	.539230	59	265	30	0
60	1.000000	60	.500000	60	270	00	0
61	.998459	61	.460770	61	274	30	0
62	.993844	62	.421783	62	279	00	0
63	.986185	63	.383277	63	283	30	0
64	.975528	64	.345492	64	288	00	0
65	.961940	65	.308658	65	292	30	0
66	.945503	66	.273005	66	297	00	0
67	.926320	67	.238751	67	301	30	0
68	.904508	68	.206107	68	306	00	0
69	.880203	69	.175276	69	310	30	0
70	.853553	70	.146447	70	315	00	0
71	.824724	71	.119797	71	319	30	0
72	.793893	72	.095492	72	324	00	0
73	.761249	73	.073680	73	328	30	0
74	.726995	74	.054497	74	333	00	0
75	.691342	75	.038060	75	337	30	0
76	.654508	76	.024472	76	342	00	0
77	.616723	77	.013815	77	346	30	0
78	.578217	78	.006156	78	351	00	0
79	.539230	79	.001541	79	355	30	0
80	.500000	80	.000000	80	360	0	0

81 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

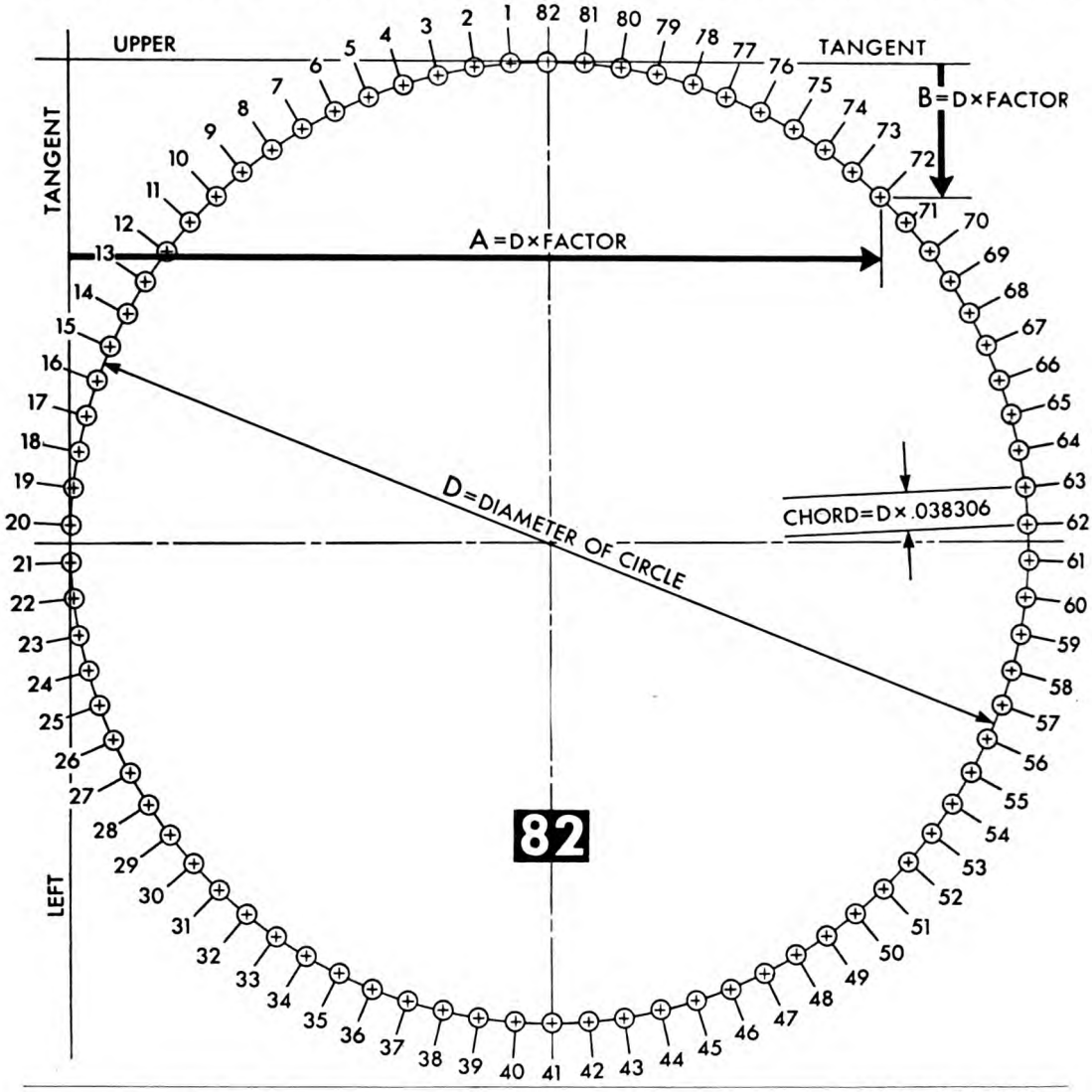


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.461254	1	.001504	1	4	26	40
2	.422741	2	.006005	2	8	53	20
3	.384692	3	.013478	3	13	20	00
4	.347337	4	.023876	4	17	46	40
5	.310900	5	.037138	5	22	13	20
6	.275600	6	.053184	6	26	40	00
7	.241650	7	.071917	7	31	6	40
8	.209254	8	.093224	8	35	33	20
9	.178606	9	.116978	9	40	00	00
10	.149891	10	.143035	10	44	26	40
11	.123282	11	.171239	11	48	53	20
12	.098938	12	.201421	12	53	20	00
13	.077007	13	.233398	13	57	46	40
14	.057619	14	.266978	14	62	13	20
15	.040892	15	.301960	15	66	40	00
16	.026926	16	.338133	16	71	6	40
17	.015805	17	.375279	17	75	33	20

COORDINATE FACTORS AND ANGLES—81 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
18	.007596	18	.413176	18	80	00	00
19	.002349	19	.451595	19	84	26	40
20	.000094	20	.490304	20	88	53	20
21	.000846	21	.529072	21	93	20	00
22	.004600	22	.567666	22	97	46	40
23	.011333	23	.605852	23	102	13	20
24	.021005	24	.643402	24	106	40	00
25	.033558	25	.680089	25	111	6	40
26	.048916	26	.715693	26	115	33	20
27	.066987	27	.750000	27	120	00	00
28	.087663	28	.782803	28	124	26	40
29	.110818	29	.813907	29	128	53	20
30	.136313	30	.843121	30	133	20	00
31	.163996	31	.870272	31	137	46	40
32	.193700	32	.895196	32	142	13	20
33	.225246	33	.917744	33	146	40	00
34	.258444	34	.937779	34	151	6	40
35	.293095	35	.955181	35	155	33	20
36	.328990	36	.969846	36	160	00	00
37	.365914	37	.981685	37	164	26	40
38	.403644	38	.990628	38	168	53	20
39	.441954	39	.996619	39	173	20	00
40	.480612	40	.999624	40	177	46	40
41	.519388	41	.999624	41	182	13	20
42	.558046	42	.996619	42	186	40	00
43	.596356	43	.990628	43	191	6	40
44	.634086	44	.981685	44	195	33	20
45	.671010	45	.969846	45	200	00	00
46	.706905	46	.955181	46	204	26	40
47	.741556	47	.937779	47	208	53	20
48	.774754	48	.917744	48	213	20	00
49	.806300	49	.895196	49	217	46	40
50	.836004	50	.870272	50	222	13	20
51	.863687	51	.843121	51	226	40	00
52	.889182	52	.813907	52	231	6	40
53	.912338	53	.782803	53	235	33	20
54	.933013	54	.750000	54	240	00	00
55	.951084	55	.715693	55	244	26	40
56	.966442	56	.680089	56	248	53	20
57	.978995	57	.643402	57	253	20	00
58	.988667	58	.605852	58	257	46	40
59	.995400	59	.567666	59	262	13	20
60	.999154	60	.529072	60	266	40	00
61	.999906	61	.490304	61	271	6	40
62	.997651	62	.451595	62	275	33	20
63	.992404	63	.413176	63	280	00	00
64	.984195	64	.375279	64	284	26	40
65	.973074	65	.338133	65	288	53	20
66	.959108	66	.301960	66	293	20	00
67	.942381	67	.266978	67	297	46	40
68	.922993	68	.233398	68	302	13	20
69	.901062	69	.201421	69	306	40	00
70	.876718	70	.171239	70	311	6	40
71	.850109	71	.143035	71	315	33	20
72	.821394	72	.116978	72	320	00	00
73	.790746	73	.093224	73	324	26	40
74	.758350	74	.071917	74	328	53	20
75	.724400	75	.053184	75	333	20	00
76	.689100	76	.037138	76	337	46	40
77	.652663	77	.023876	77	342	13	20
78	.615308	78	.013478	78	346	40	00
79	.577259	79	.006005	79	351	6	40
80	.538746	80	.001504	80	355	33	20
81	.500000	81	.000000	81	360	0	0

82 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

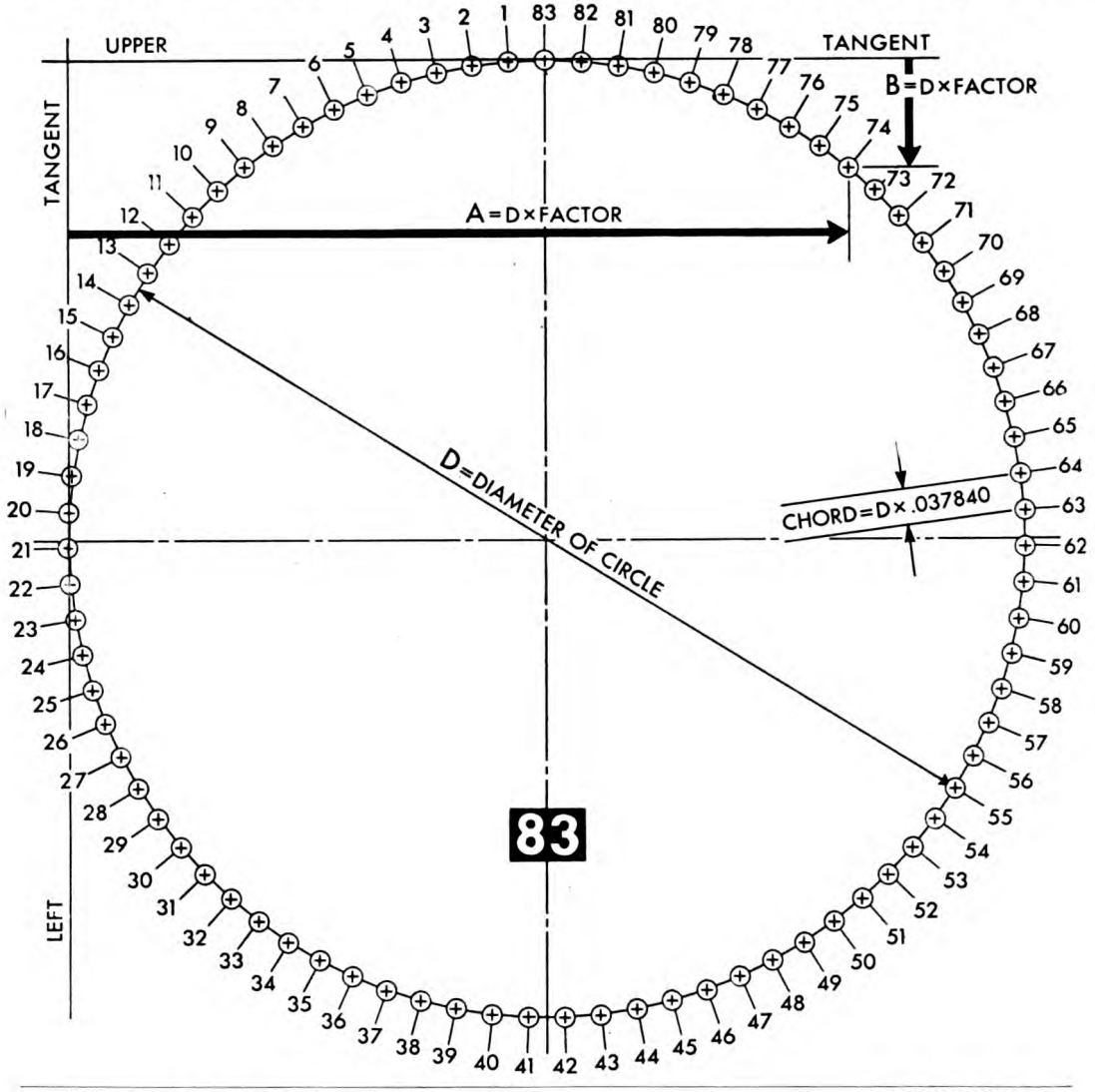


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.461725	1	.001467	1	4	23	24-72/82
2	.423675	2	.005860	2	8	46	49-62/82
3	.386073	3	.013152	3	13	10	14-52/82
4	.349140	4	.023302	4	17	33	39-42/82
5	.313091	5	.036249	5	21	57	4-32/82
6	.278140	6	.051917	6	26	20	29-22/82
7	.244491	7	.070215	7	30	43	54-12/82
8	.212341	8	.091035	8	35	7	19- 2/82
9	.181879	9	.114255	9	39	30	43-74/82
10	.153284	10	.139739	10	43	54	8-64/82
11	.126723	11	.167337	11	48	17	33-54/82
12	.102354	12	.196887	12	52	40	58-44/82
13	.080317	13	.228216	13	57	4	23-34/82
14	.060744	14	.261140	14	61	27	48-24/82
15	.043748	15	.295466	15	65	51	13-14/82
16	.029430	16	.330992	16	70	14	38- 4/82
17	.017873	17	.367509	17	74	38	2-76/82

COORDINATE FACTORS AND ANGLES—82 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
18	.009146	18	.404804	18	79	1	27-66/82
19	.003299	19	.442658	19	83	24	52-56/82
20	.000367	20	.480849	20	87	48	17-46/82
21	.000367	21	.519151	21	92	11	42-36/82
22	.003299	22	.557342	22	96	35	7-26/82
23	.009146	23	.595196	23	100	58	32-16/82
24	.017873	24	.632491	24	105	21	57- 6/82
25	.029430	25	.669008	25	109	45	21-78/82
26	.043748	26	.704534	26	114	8	46-68/82
27	.060744	27	.738860	27	118	32	11-58/82
28	.080317	28	.771784	28	122	55	36-48/82
29	.102354	29	.803113	29	127	19	1-38/82
30	.126723	30	.832663	30	131	42	26-28/82
31	.153284	31	.860261	31	136	5	51-18/82
32	.181879	32	.885745	32	140	29	16- 8/82
33	.212341	33	.908965	33	144	52	40-80/82
34	.244491	34	.929785	34	149	16	5-70/82
35	.278140	35	.948083	35	153	39	30-60/82
36	.313091	36	.963751	36	158	2	55-50/82
37	.349140	37	.976698	37	162	26	20-40/82
38	.386073	38	.986848	38	166	49	45-30/82
39	.423675	39	.994140	39	171	13	10-20/82
40	.461725	40	.998533	40	175	36	35-10/82
41	.500000	41	1.000000	41	180	00	00000000
42	.538275	42	.998533	42	184	23	24-72/82
43	.576325	43	.994140	43	188	46	49-62/82
44	.613927	44	.986848	44	193	10	14-52/82
45	.650860	45	.976698	45	197	33	39-42/82
46	.686909	46	.963751	46	201	57	4-32/82
47	.721860	47	.948083	47	206	20	29-22/82
48	.755509	48	.929785	48	210	43	54-12/82
49	.787659	49	.908965	49	215	7	19- 2/82
50	.818121	50	.885745	50	219	30	43-74/82
51	.846716	51	.860261	51	223	54	8-64/82
52	.873277	52	.832663	52	228	17	33-54/82
53	.897646	53	.803113	53	232	40	58-44/82
54	.919683	54	.771784	54	237	4	23-34/82
55	.939256	55	.738860	55	241	27	48-24/82
56	.956252	56	.704534	56	245	51	13-14/82
57	.970570	57	.669008	57	250	14	38- 4/82
58	.982127	58	.632491	58	254	38	2-76/82
59	.990854	59	.595196	59	259	1	27-66/82
60	.996701	60	.557342	60	263	24	52-56/82
61	.999633	61	.519151	61	267	48	17-46/82
62	.999633	62	.480849	62	272	11	42-36/82
63	.996701	63	.442658	63	276	35	7-26/82
64	.990854	64	.404804	64	280	58	32-16/82
65	.982127	65	.367509	65	285	21	57- 6/82
66	.970570	66	.330992	66	289	45	21-78/82
67	.956252	67	.295466	67	294	8	46-68/82
68	.939256	68	.261140	68	298	32	11-58/82
69	.919683	69	.228216	69	302	55	36-48/82
70	.897646	70	.196887	70	307	19	1-38/82
71	.873277	71	.167337	71	311	42	26-28/82
72	.846716	72	.139739	72	316	5	51-18/82
73	.818121	73	.114255	73	320	29	16- 8/82
74	.787659	74	.091035	74	324	52	40-80/82
75	.755509	75	.070215	75	329	16	5-70/82
76	.721860	76	.051917	76	333	39	30-60/82
77	.686909	77	.036249	77	338	2	55-50/82
78	.650860	78	.023302	78	342	26	20-40/82
79	.613927	79	.013152	79	346	49	45-30/82
80	.576325	80	.005859	80	351	13	10-20/82
81	.538275	81	.001467	81	355	36	35-10/82
82	.500000	82	.000000	82	360	0	0

83 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

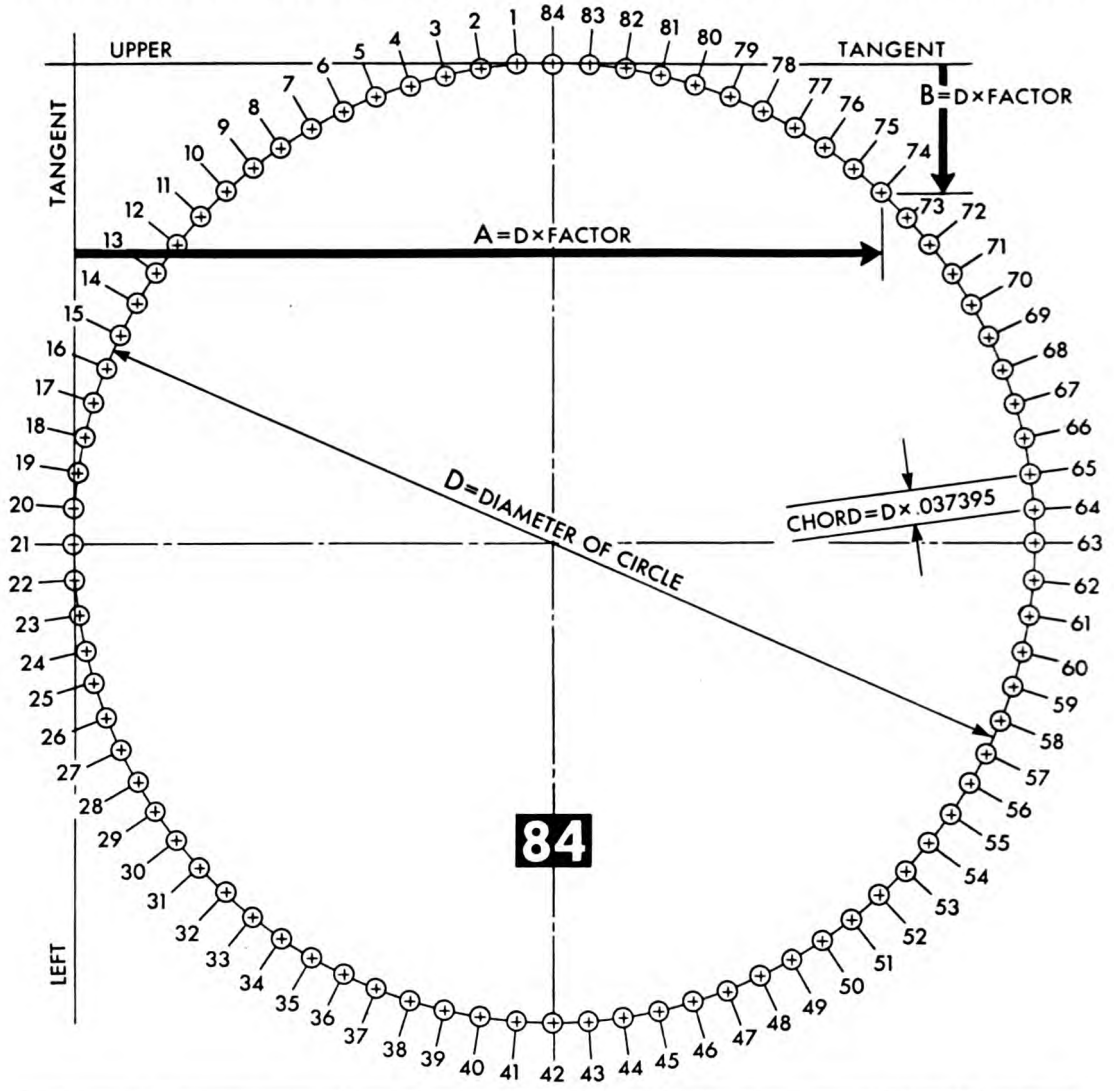


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.462186	1	.001432	1	4	20	14-38/83
2	.424588	2	.005720	2	8	40	28-76/83
3	.387422	3	.012838	3	13	00	43-31/83
4	.350901	4	.022748	4	17	20	57-69/83
5	.315234	5	.035391	5	21	41	12-24/83
6	.280625	6	.050695	6	26	1	26-62/83
7	.247273	7	.068573	7	30	21	41-17/83
8	.215369	8	.088922	8	34	41	55-55/83
9	.185095	9	.111626	9	39	2	10-10/83
10	.156624	10	.136554	10	43	22	24-48/83
11	.130121	11	.163564	11	47	42	39- 3/83
12	.105736	12	.192501	12	52	2	53-41/83
13	.083609	13	.223199	13	56	23	7-79/83
14	.063868	14	.255483	14	60	43	22-34/83
15	.046624	15	.289167	15	65	3	36-72/83
16	.031978	16	.324059	16	69	23	51-27/83
17	.020012	17	.359959	17	73	44	5-65/83

COORDINATE FACTORS AND ANGLES—83 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
18	.010795	18	.396661	18	78	4	20-20/83
19	.004381	19	.433955	19	82	24	34-58/83
20	.000806	20	.471627	20	86	44	49-13/83
21	.000090	21	.509462	21	91	5	3-51/83
22	.002237	22	.547243	22	95	25	18- 6/83
23	.007235	23	.584752	23	99	45	32-44/83
24	.015056	24	.621777	24	104	5	46-82/83
25	.025655	25	.658104	25	108	26	1-37/83
26	.038971	26	.693525	26	112	46	15-75/83
27	.054927	27	.727838	27	117	6	30-30/83
28	.073433	28	.760846	28	121	26	44-68/83
29	.094382	29	.792359	29	125	46	59-23/83
30	.117654	30	.822199	30	130	7	13-61/83
31	.143117	31	.850192	31	134	27	28-16/83
32	.170624	32	.876180	32	138	47	42-54/83
33	.200017	33	.900013	33	143	7	57- 9/83
34	.231129	34	.921554	34	147	28	11-47/83
35	.263780	35	.940682	35	151	48	26- 2/83
36	.297785	36	.957284	36	156	8	40-40/83
37	.332948	37	.971268	37	160	28	54-78/83
38	.369068	38	.982552	38	164	49	9-33/83
39	.405938	39	.991073	39	169	9	23-71/83
40	.443346	40	.996780	40	173	29	38-26/83
41	.481079	41	.999642	41	177	49	52-64/83
42	.518921	42	.999642	42	182	10	7-19/83
43	.556654	43	.996780	43	186	30	21-57/83
44	.594062	44	.991073	44	190	50	36-12/83
45	.630932	45	.982552	45	195	10	50-50/83
46	.667052	46	.971268	46	199	31	5- 5/83
47	.702215	47	.957284	47	203	51	19-43/83
48	.736220	48	.940682	48	208	11	33-81/83
49	.768871	49	.921554	49	212	31	48-36/83
50	.799983	50	.900013	50	216	52	2-74/83
51	.829376	51	.876180	51	221	12	17-29/83
52	.856883	52	.850192	52	225	32	31-67/83
53	.882346	53	.822199	53	229	52	46-22/83
54	.905618	54	.792359	54	234	13	00-60/83
55	.926567	55	.760846	55	238	33	15-15/83
56	.945073	56	.727838	56	242	53	29-53/83
57	.961029	57	.693525	57	247	13	44- 8/83
58	.974345	58	.658104	58	251	33	58-46/83
59	.984944	59	.621777	59	255	54	13- 1/83
60	.992765	60	.584752	60	260	14	27-39/83
61	.997763	61	.547243	61	264	34	41-77/83
62	.999910	62	.509462	62	268	54	56-32/83
63	.999194	63	.471627	63	273	15	10-70/83
64	.995619	64	.433955	64	277	35	25-25/83
65	.989205	65	.396661	65	281	55	39-63/83
66	.979988	66	.359959	66	286	15	54-18/83
67	.968022	67	.324059	67	290	36	8-56/83
68	.953376	68	.289167	68	294	56	23-11/83
69	.936132	69	.255483	69	299	16	37-49/83
70	.916391	70	.223199	70	303	36	52- 4/83
71	.894264	71	.192501	71	307	57	6-42/83
72	.869879	72	.163564	72	312	17	20-80/83
73	.843376	73	.136554	73	316	37	35-35/83
74	.814905	74	.111626	74	320	57	49-73/83
75	.784631	75	.088922	75	325	18	4-28/83
76	.752727	76	.068573	76	329	38	18-66/83
77	.719375	77	.050695	77	333	58	33-21/83
78	.684766	78	.035391	78	338	18	47-59/83
79	.649099	79	.022748	79	342	39	2-14/83
80	.612578	80	.012838	80	346	59	16-52/83
81	.575412	81	.005720	81	351	19	31- 7/83
82	.537814	82	.001432	82	355	39	45-45/83
83	.500000	83	.000000	83	360	0	0

84 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

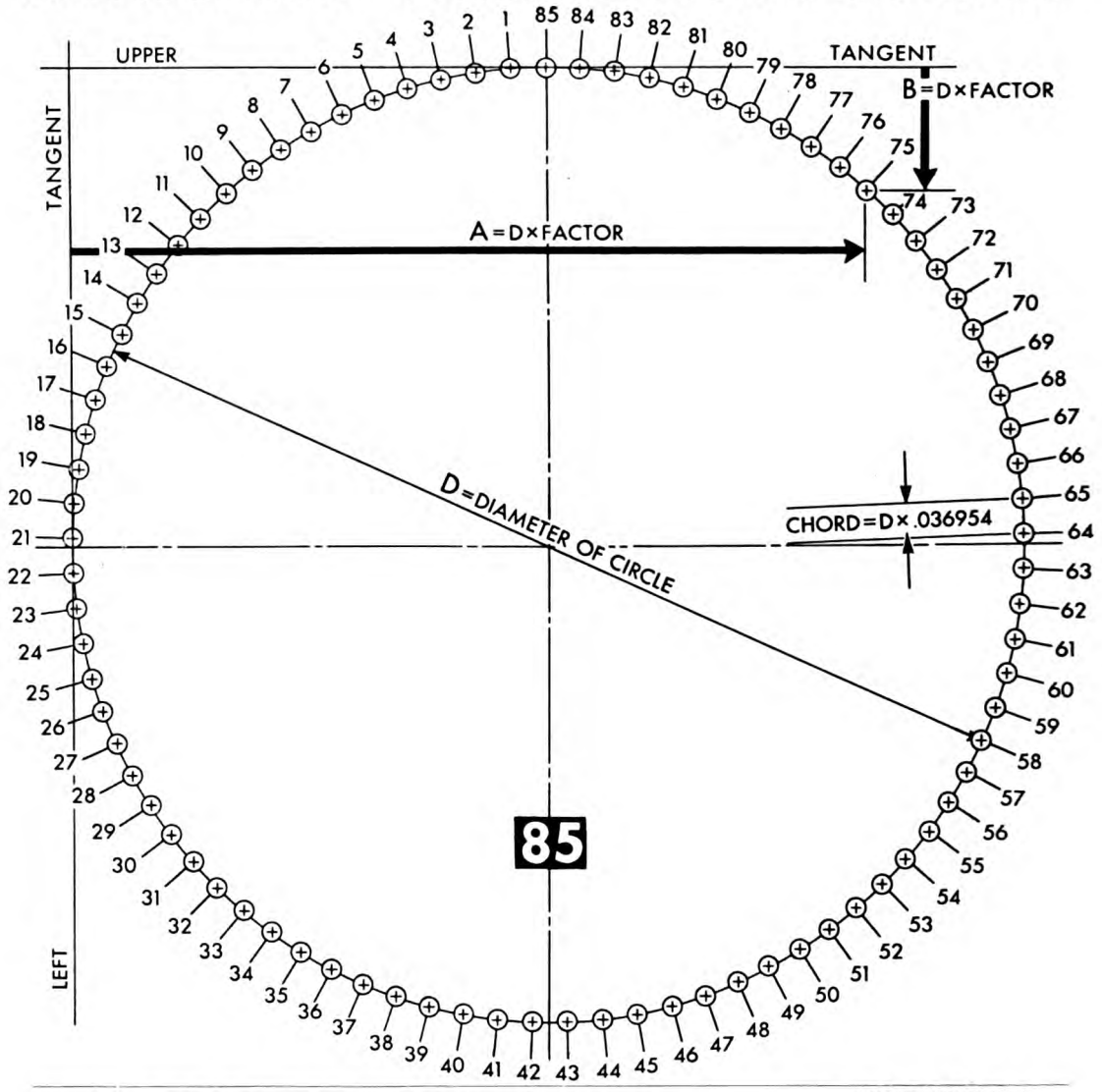


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.462635	1	.001398	1	4	17	8-48/84
2	.425479	2	.005585	2	8	34	17-12/84
3	.388740	3	.012536	3	12	51	25-60/84
4	.352622	4	.022214	4	17	8	34-24/84
5	.317329	5	.034563	5	21	25	42-72/84
6	.283058	6	.049516	6	25	42	51-36/84
7	.250000	7	.066987	7	30	00	00000000
8	.218340	8	.086881	8	34	17	8-48/84
9	.188255	9	.109084	9	38	34	17-12/84
10	.159914	10	.133474	10	42	51	25-60/84
11	.133474	11	.159914	11	47	8	34-24/84
12	.109084	12	.188255	12	51	25	42-72/84
13	.086881	13	.218340	13	55	42	51-36/84
14	.066987	14	.250000	14	60	00	00000000
15	.049516	15	.283058	15	64	17	8-48/84
16	.034563	16	.317329	16	68	34	17-12/84
17	.022214	17	.352622	17	72	51	25-60/84

COORDINATE FACTORS AND ANGLES—84 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
18	.012536	18	.388740	18	77	8	34-24/84
19	.005585	19	.425479	19	81	25	42-72/84
20	.001398	20	.462635	20	85	42	51-36/84
21	.000000	21	.500000	21	90	00	00000000
22	.001398	22	.537365	22	94	17	8-48/84
23	.005584	23	.574521	23	98	34	17-12/84
24	.012536	24	.611260	24	102	51	25-60/84
25	.022214	25	.647378	25	107	8	34-24/84
26	.034563	26	.682671	26	111	25	42-72/84
27	.049516	27	.716942	27	115	42	51-36/84
28	.066987	28	.750000	28	120	00	00000000
29	.086881	29	.781660	29	124	17	8-48/84
30	.109084	30	.811745	30	128	34	17-12/84
31	.133474	31	.840086	31	132	51	25-60/84
32	.159914	32	.866526	32	137	8	34-24/84
33	.188255	33	.890916	33	141	25	42-72/84
34	.218340	34	.913119	34	145	42	51-36/84
35	.250000	35	.933013	35	150	00	00000000
36	.283058	36	.950484	36	154	17	8-48/84
37	.317329	37	.965437	37	158	34	17-12/84
38	.352622	38	.977786	38	162	51	25-60/84
39	.388740	39	.987464	39	167	8	34-24/84
40	.425479	40	.994415	40	171	25	42-72/84
41	.462635	41	.998602	41	175	42	51-36/84
42	.500000	42	1.000000	42	180	00	00000000
43	.537365	43	.998602	43	184	17	8-48/84
44	.574521	44	.994415	44	188	34	17-12/84
45	.611260	45	.987464	45	192	51	25-60/84
46	.647378	46	.977786	46	197	8	34-24/84
47	.682671	47	.965437	47	201	25	42-72/84
48	.716942	48	.950484	48	205	42	51-36/84
49	.750000	49	.933013	49	210	00	00000000
50	.781660	50	.913119	50	214	17	8-48/84
51	.811745	51	.890916	51	218	34	17-12/84
52	.840086	52	.866526	52	222	51	25-60/84
53	.866526	53	.840086	53	227	8	34-24/84
54	.890916	54	.811745	54	231	25	42-72/84
55	.913119	55	.781660	55	235	42	51-36/84
56	.933013	56	.750000	56	240	00	00000000
57	.950484	57	.716942	57	244	17	8-48/84
58	.965437	58	.682671	58	248	34	17-12/84
59	.977786	59	.647378	59	252	51	25-60/84
60	.987464	60	.611260	60	257	8	34-24/84
61	.994415	61	.574521	61	261	25	42-72/84
62	.998602	62	.537365	62	265	42	51-36/84
63	1.000000	63	.500000	63	270	00	00000000
64	.998602	64	.462635	64	274	17	8-48/84
65	.994415	65	.425479	65	278	34	17-12/84
66	.987464	66	.388740	66	282	51	25-60/84
67	.977786	67	.352622	67	287	8	34-24/84
68	.965437	68	.317329	68	291	25	42-72/84
69	.950484	69	.283058	69	295	42	51-36/84
70	.933013	70	.250000	70	300	00	00000000
71	.913119	71	.218340	71	304	17	8-48/84
72	.890916	72	.188255	72	308	34	17-12/84
73	.866526	73	.159914	73	312	51	25-60/84
74	.840086	74	.133474	74	317	8	34-24/84
75	.811745	75	.109084	75	321	25	42-72/84
76	.781660	76	.086881	76	325	42	51-36/84
77	.750000	77	.066987	77	330	00	00000000
78	.716942	78	.049516	78	334	17	8-48/84
79	.682671	79	.034563	79	338	34	17-12/84
80	.647378	80	.022214	80	342	51	25-60/84
81	.611260	81	.012536	81	347	8	34-24/84
82	.574521	82	.005585	82	351	25	42-72/84
83	.537365	83	.001398	83	355	42	51-36/84
84	.500000	84	.000000	84	360	0	0

85 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

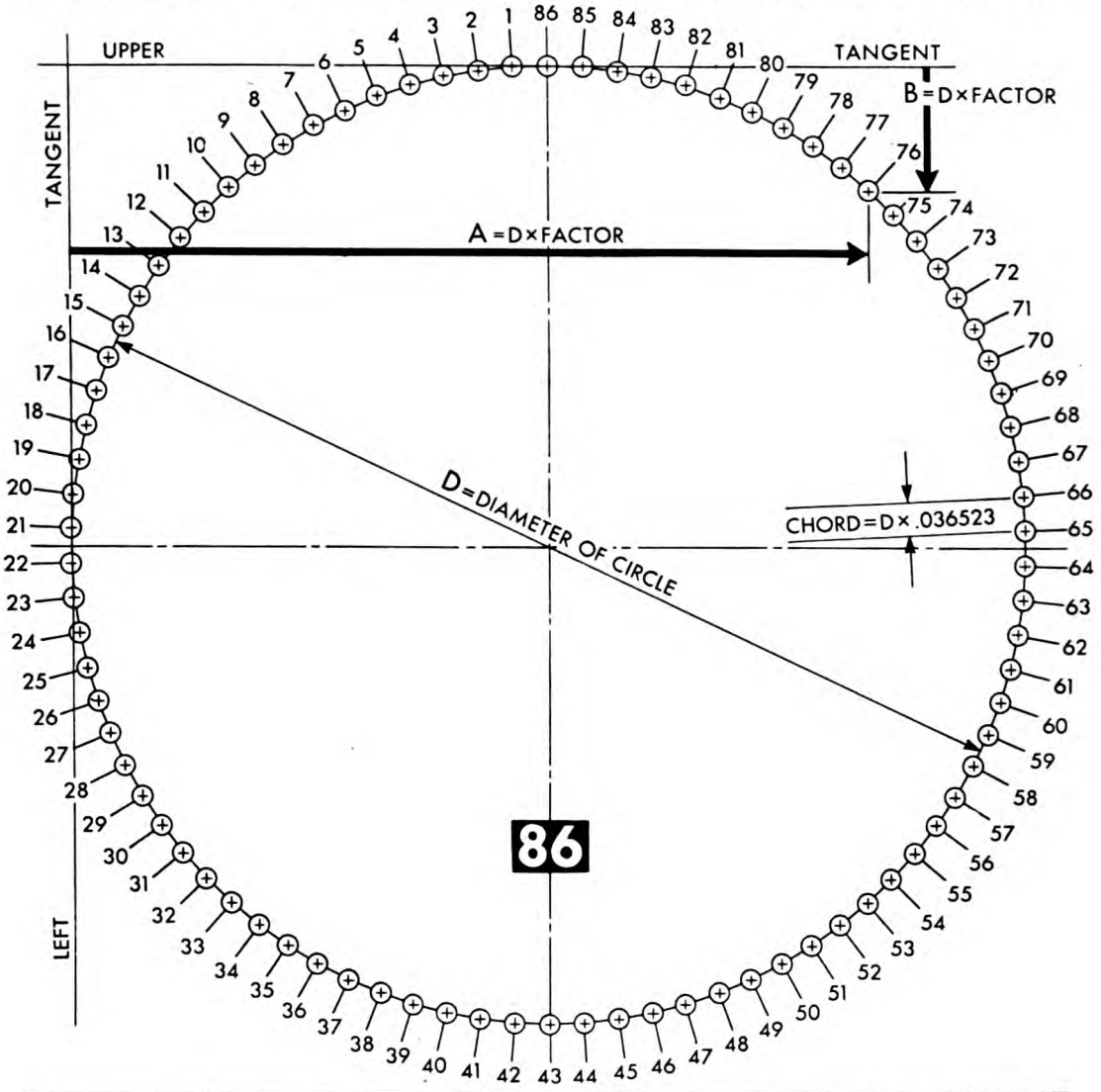


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.463074	1	.001365	1	4	14	7- 5/85
2	.426349	2	.005454	2	8	28	14-10/85
3	.390027	3	.012244	3	12	42	21-15/85
4	.354305	4	.021697	4	16	56	28-20/85
5	.319379	5	.033764	5	21	10	35-25/85
6	.285440	6	.048376	6	25	24	42-30/85
7	.252672	7	.065456	7	29	38	49-35/85
8	.221255	8	.084908	8	33	52	56-40/85
9	.191361	9	.106628	9	38	7	3-45/85
10	.163152	10	.130496	10	42	21	10-50/85
11	.136783	11	.156382	11	46	35	17-55/85
12	.112398	12	.184145	12	50	49	24-60/85
13	.090130	13	.213632	13	55	3	31-65/85
14	.070100	14	.244684	14	59	17	38-70/85
15	.052418	15	.277131	15	63	31	45-75/85
16	.037181	16	.310794	16	67	45	52-80/85
17	.024472	17	.345492	17	72	00	00000000

COORDINATE FACTORS AND ANGLES—85 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
18	.014359	18	.381032	18	76	14	7– 5/85
19	.006900	19	.417223	19	80	28	14–10/85
20	.002133	20	.453866	20	84	42	21–15/85
21	.000085	21	.490760	21	88	56	28–20/85
22	.000768	22	.527705	22	93	10	35–25/85
23	.004178	23	.564500	23	97	24	42–30/85
24	.010295	24	.600941	24	101	38	49–35/85
25	.019087	25	.636832	25	105	52	56–40/85
26	.030506	26	.671974	26	110	7	3–45/85
27	.044489	27	.706178	27	114	21	10–50/85
28	.060959	28	.739256	28	118	35	17–55/85
29	.079828	29	.771027	29	122	49	24–60/85
30	.100991	30	.801317	30	127	3	31–65/85
31	.124334	31	.829962	31	131	17	38–70/85
32	.149728	32	.856805	32	135	31	45–75/85
33	.177036	33	.881699	33	139	45	52–80/85
34	.206107	34	.904508	34	144	00	00000000
35	.236784	35	.925109	35	148	14	7– 5/85
36	.268898	36	.943387	36	152	28	14–10/85
37	.302274	37	.959243	37	156	42	21–15/85
38	.336731	38	.972592	38	160	56	28–20/85
39	.372079	39	.983359	39	165	10	35–25/85
40	.408125	40	.991487	40	169	24	42–30/85
41	.444672	41	.996930	41	173	38	49–35/85
42	.481524	42	.999659	42	177	52	56–40/85
43	.518476	43	.999659	43	182	7	3–45/85
44	.555328	44	.996930	44	186	21	10–50/85
45	.591875	45	.991487	45	190	35	17–55/85
46	.627921	46	.983359	46	194	49	24–60/85
47	.663269	47	.972592	47	199	3	31–65/85
48	.697726	48	.959243	48	203	17	38–70/85
49	.731102	49	.943387	49	207	31	45–75/85
50	.763216	50	.925109	50	211	45	52–80/85
51	.793893	51	.904508	51	216	00	00000000
52	.822964	52	.881699	52	220	14	7– 5/85
53	.850272	53	.856805	53	224	28	14–10/85
54	.875666	54	.829962	54	228	42	21–15/85
55	.899009	55	.801317	55	232	56	28–20/85
56	.920172	56	.771027	56	237	10	35–25/85
57	.939041	57	.739256	57	241	24	42–30/85
58	.955511	58	.706178	58	245	38	49–35/85
59	.969494	59	.671974	59	249	52	56–40/85
60	.980913	60	.636832	60	254	7	3–45/85
61	.989705	61	.600941	61	258	21	10–50/85
62	.995822	62	.564500	62	262	35	17–55/85
63	.999232	63	.527705	63	266	49	24–60/85
64	.999915	64	.490760	64	271	3	31–65/85
65	.997867	65	.453866	65	275	17	38–70/85
66	.993100	66	.417223	66	279	31	45–75/85
67	.985641	67	.381032	67	283	45	52–80/85
68	.975528	68	.345492	68	288	00	00000000
69	.962819	69	.310794	69	292	14	7– 5/85
70	.947582	70	.277131	70	296	28	14–10/85
71	.929900	71	.244684	71	300	42	21–15/85
72	.909870	72	.213632	72	304	56	28–20/85
73	.887602	73	.184145	73	309	10	35–25/85
74	.863217	74	.156382	74	313	24	42–30/85
75	.836848	75	.130496	75	317	38	49–35/85
76	.808639	76	.106628	76	321	52	56–40/85
77	.778745	77	.084908	77	326	7	3–45/85
78	.747328	78	.065456	78	330	21	10–50/85
79	.714560	79	.048376	79	334	35	17–55/85
80	.680621	80	.033764	80	338	49	24–60/85
81	.645695	81	.021697	81	343	3	31–65/85
82	.609973	82	.012244	82	347	17	38–70/85
83	.573651	83	.005454	83	351	31	45–75/85
84	.536926	84	.001365	84	355	45	52–80/85
85	.500000	85	.000000	85	360	0	0

86 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

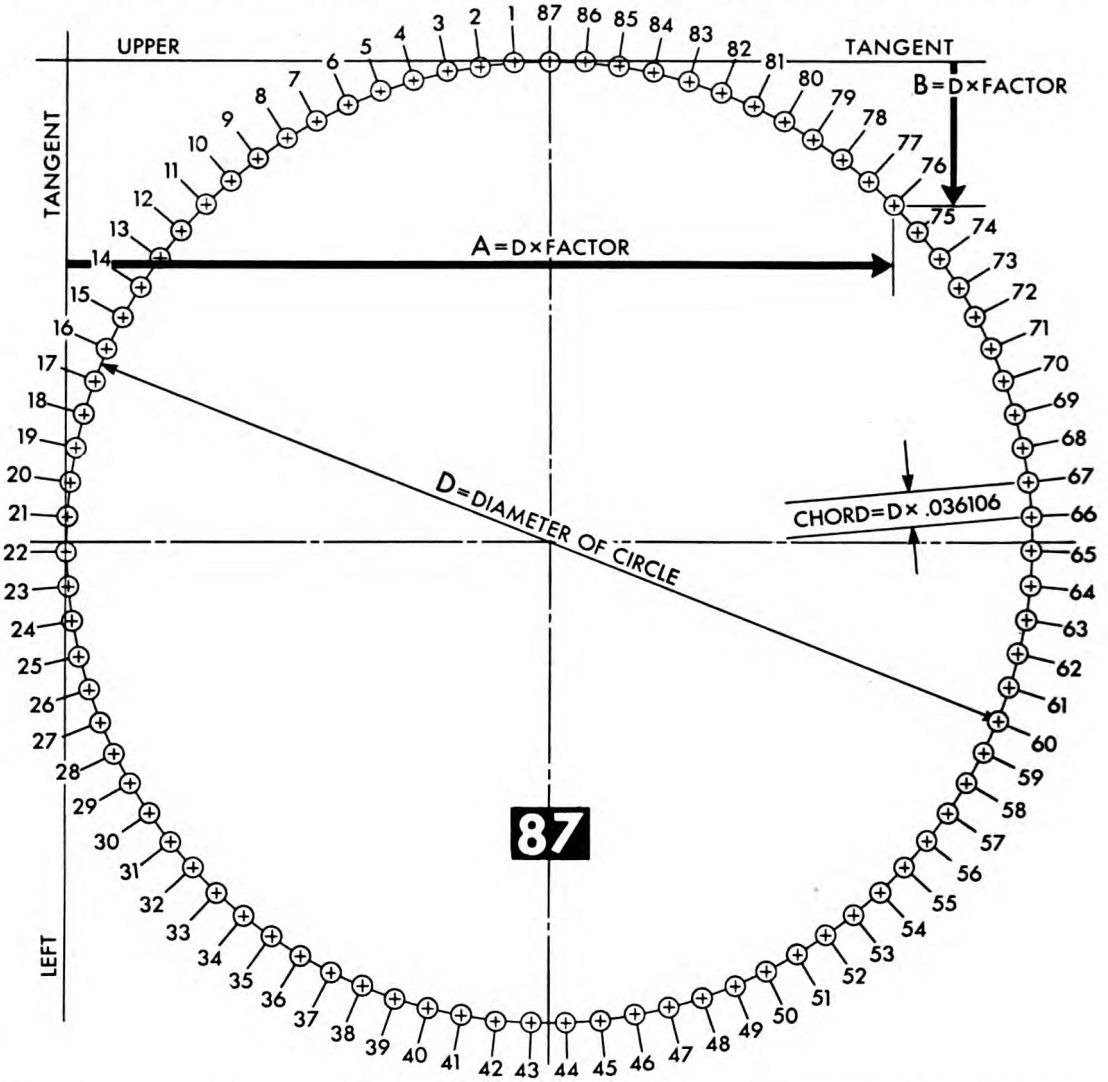


→ FACTOR FOR "A"		FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
1	.463502	1	.001334	1	4	11	9-66/86
2	.427199	2	.005328	2	8	22	19-46/86
3	.391285	3	.011962	3	12	33	29-26/86
4	.355950	4	.021200	4	16	44	39- 6/86
5	.321384	5	.032992	5	20	55	48-72/86
6	.287772	6	.047276	6	25	6	58-52/86
7	.255291	7	.063975	7	29	18	8-32/86
8	.224116	8	.083001	8	33	29	18-12/86
9	.194413	9	.104252	9	37	40	27-78/86
10	.166342	10	.127614	10	41	51	37-58/86
11	.140048	11	.152963	11	46	2	47-38/86
12	.115676	12	.180163	12	50	13	57-18/86
13	.093355	13	.209071	13	54	25	6-84/86
14	.073203	14	.239530	14	58	36	16-64/86
15	.055329	15	.271379	15	62	47	26-44/86
16	.039827	16	.304448	16	66	58	36-24/86
17	.026780	17	.338560	17	71	9	46- 4/86

COORDINATE FACTORS AND ANGLES—86 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
18	.016258	18	.373533	18	75	20	55–70/86
19	.008317	19	.409182	19	79	32	5–50/86
20	.003000	20	.445314	20	83	43	15–30/86
21	.000334	21	.481739	21	87	54	25–10/86
22	.000334	22	.518261	22	92	5	34–76/86
23	.003000	23	.554686	23	96	16	44–56/86
24	.008317	24	.590818	24	100	27	54–36/86
25	.016258	25	.626467	25	104	39	4–16/86
26	.026780	26	.661440	26	108	50	13–82/86
27	.039827	27	.695552	27	113	1	23–62/86
28	.055329	28	.728621	28	117	12	33–42/86
29	.073203	29	.760470	29	121	23	43–22/86
30	.093355	30	.790929	30	125	34	53– 2/86
31	.115676	31	.819837	31	129	46	2–68/86
32	.140048	32	.847037	32	133	57	12–48/86
33	.166342	33	.872386	33	138	8	22–28/86
34	.194413	34	.895748	34	142	19	32– 8/86
35	.224116	35	.916999	35	146	30	41–74/86
36	.255291	36	.936025	36	150	41	51–54/86
37	.287772	37	.952724	37	154	53	1–34/86
38	.321384	38	.967008	38	159	4	11–14/86
39	.355950	39	.978800	39	163	15	20–80/86
40	.391285	40	.988038	40	167	26	30–60/86
41	.427199	41	.994672	41	171	37	40–40/86
42	.463502	42	.998666	42	175	48	50–20/86
43	.500000	43	1.000000	43	180	00	00000000
44	.536498	44	.998666	44	184	11	9–66/86
45	.572801	45	.994672	45	188	22	19–46/86
46	.608715	46	.988038	46	192	33	29–26/86
47	.644050	47	.978800	47	196	44	39– 6/86
48	.678616	48	.967008	48	200	55	48–72/86
49	.712228	49	.952724	49	205	6	58–52/86
50	.744709	50	.936025	50	209	18	8–32/86
51	.775884	51	.916999	51	213	29	18–12/86
52	.805587	52	.895748	52	217	40	27–78/86
53	.833658	53	.872386	53	221	51	37–58/86
54	.859952	54	.847037	54	226	2	47–38/86
55	.884324	55	.819837	55	230	13	57–18/86
56	.906645	56	.790929	56	234	25	6–84/86
57	.926797	57	.760470	57	238	36	16–64/86
58	.944671	58	.728621	58	242	47	26–44/86
59	.960173	59	.695552	59	246	58	36–24/86
60	.973220	60	.661440	60	251	9	46– 4/86
61	.983742	61	.626467	61	255	20	55–70/86
62	.991683	62	.590818	62	259	32	5–50/86
63	.997000	63	.554686	63	263	43	15–30/86
64	.999666	64	.518261	64	267	54	25–10/86
65	.999666	65	.481739	65	272	5	34–76/86
66	.997000	66	.445314	66	276	16	44–56/86
67	.991683	67	.409182	67	280	27	54–36/86
68	.983742	68	.373533	68	284	39	4–16/86
69	.973220	69	.338560	69	288	50	13–82/86
70	.960173	70	.304448	70	293	1	23–62/86
71	.944671	71	.271379	71	297	12	33–42/86
72	.926797	72	.239530	72	301	23	43–22/86
73	.906645	73	.209071	73	305	34	53– 2/86
74	.884324	74	.180163	74	309	46	2–68/86
75	.859952	75	.152963	75	313	57	12–48/86
76	.833658	76	.127614	76	318	8	22–28/86
77	.805587	77	.104252	77	322	19	32– 8/86
78	.775884	78	.083001	78	326	30	41–74/86
79	.744709	79	.063975	79	330	41	51–54/86
80	.712228	80	.047276	80	334	53	1–34/86
81	.678616	81	.032992	81	339	4	11–14/86
82	.644050	82	.021200	82	343	15	20–80/86
83	.608715	83	.011962	83	347	26	30–60/86
84	.572801	84	.005328	84	351	37	40–40/86
85	.536498	85	.001334	85	355	48	50–20/86
86	.500000	86	.000000	86	360	0	0

87 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

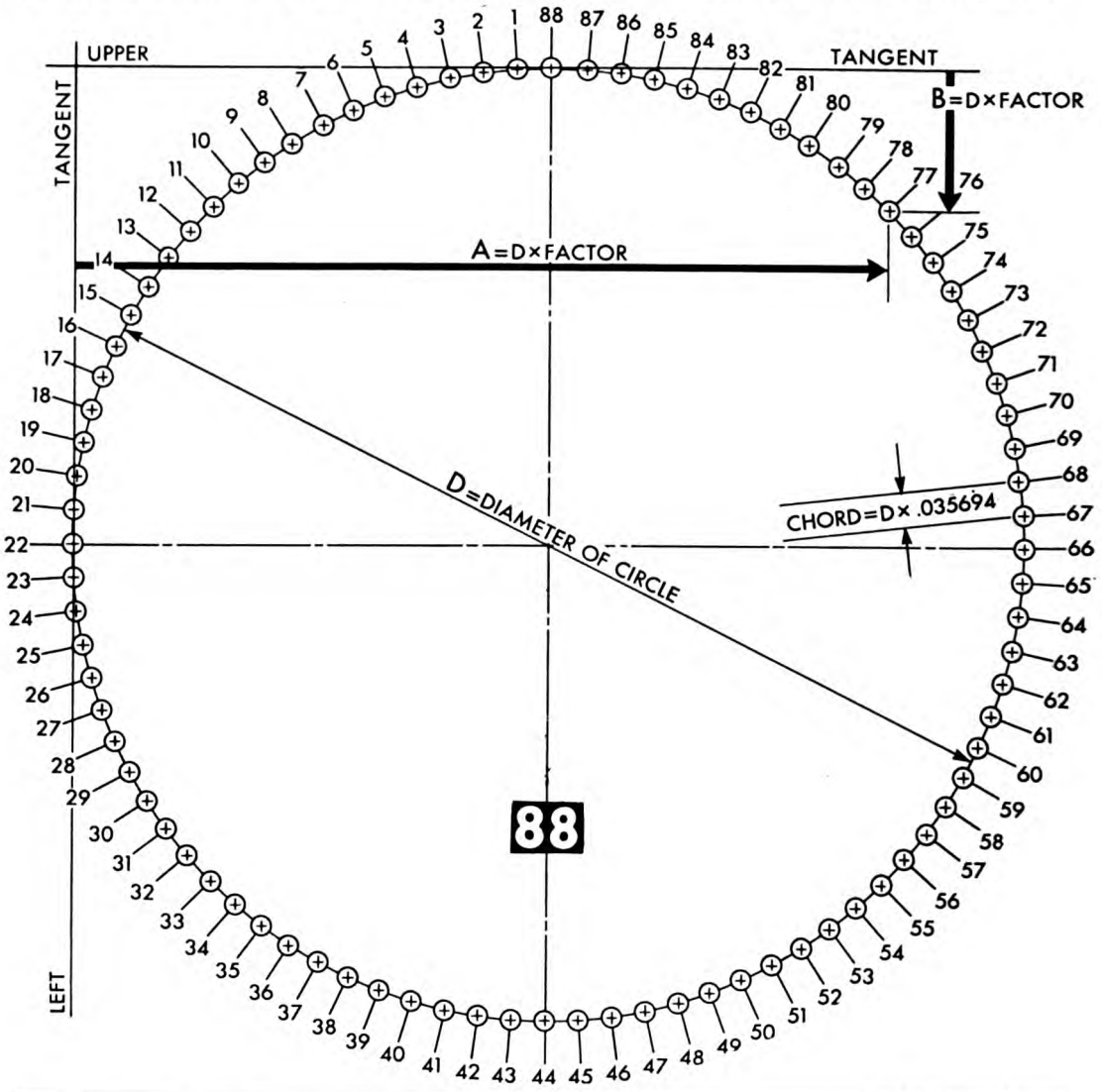


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
	→		↓		DEG.	MIN.	SEC.
1	.463921	1	.001303	1	4	8	16-48/87
2	.428030	2	.005207	2	8	16	33- 9/87
3	.392515	3	.011690	3	12	24	49-57/87
4	.357560	4	.020719	4	16	33	6-18/87
5	.323347	5	.032246	5	20	41	22-66/87
6	.290055	6	.046212	6	24	49	39-27/87
7	.257859	7	.062544	7	28	57	55-75/87
8	.226924	8	.081157	8	33	6	12-36/87
9	.197413	9	.101953	9	37	14	28-84/87
10	.169480	10	.124825	10	41	22	45-45/87
11	.143269	11	.149652	11	45	31	2- 6/87
12	.118919	12	.176307	12	49	39	18-54/87
13	.096555	13	.204649	13	53	47	35-15/87
14	.076295	14	.234530	14	57	55	51-63/87
15	.058244	15	.265796	15	62	4	8-24/87
16	.042496	16	.298283	16	66	12	24-72/87
17	.029133	17	.331821	17	70	20	41-33/87

COORDINATE FACTORS AND ANGLES—87 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
18	.018225	18	.366236	18	74	28	57-81/87
19	.009829	19	.401348	19	78	37	14-42/87
20	.003988	20	.436975	20	82	45	31- 3/87
21	.000733	21	.472931	21	86	53	47-51/87
22	.000082	22	.509027	22	91	2	4-12/87
23	.002036	23	.545077	23	95	10	20-60/87
24	.006587	24	.580891	24	99	18	37-21/87
25	.013710	25	.616284	25	103	26	53-69/87
26	.023368	26	.651071	26	107	35	10-30/87
27	.035512	27	.685069	27	111	43	26-78/87
28	.050077	28	.718103	28	115	51	43-39/87
29	.066987	29	.750000	29	120	00	00000000
30	.086156	30	.780594	30	124	8	16-48/87
31	.107481	31	.809724	31	128	16	33- 9/87
32	.130853	32	.837240	32	132	24	49-57/87
33	.156150	33	.862998	33	136	33	6-18/87
34	.183240	34	.886863	34	140	41	22-66/87
35	.211981	35	.908711	35	144	49	39-27/87
36	.242223	36	.928429	36	148	57	55-75/87
37	.273809	37	.945912	37	153	6	12-36/87
38	.306575	38	.961071	38	157	14	28-84/87
39	.340349	39	.973827	39	161	22	45-45/87
40	.374956	40	.984111	40	165	31	2- 6/87
41	.410214	41	.991872	41	169	39	18-54/87
42	.445941	42	.997069	42	173	47	35-15/87
43	.481949	43	.999674	43	177	55	51-63/87
44	.518051	44	.999674	44	182	4	8-24/87
45	.554060	45	.997069	45	186	12	24-72/87
46	.589786	46	.991872	46	190	20	41-33/87
47	.625044	47	.984111	47	194	28	57-81/87
48	.659651	48	.973827	48	198	37	14-42/87
49	.693425	49	.961071	49	202	45	31- 3/87
50	.726191	50	.945912	50	206	53	47-51/87
51	.757777	51	.928429	51	211	2	4-12/87
52	.788019	52	.908711	52	215	10	20-60/87
53	.816760	53	.886863	53	219	18	37-21/87
54	.843850	54	.862998	54	223	26	53-69/87
55	.869147	55	.837240	55	227	35	10-30/87
56	.892519	56	.809724	56	231	43	26-78/87
57	.913844	57	.780594	57	235	51	43-39/87
58	.933013	58	.750000	58	240	00	00000000
59	.949923	59	.718103	59	244	8	16-48/87
60	.964488	60	.685069	60	248	16	33- 9/87
61	.976632	61	.651071	61	252	24	49-57/87
62	.986290	62	.616284	62	256	33	6-18/87
63	.993413	63	.580891	63	260	41	22-66/87
64	.997964	64	.545077	64	264	49	39-27/87
65	.999919	65	.509027	65	268	57	55-75/87
66	.999267	66	.472931	66	273	6	12-36/87
67	.996012	67	.436975	67	277	14	28-84/87
68	.990171	68	.401348	68	281	22	45-45/87
69	.981775	69	.366236	69	285	31	2- 6/87
70	.970867	70	.331821	70	289	39	18-54/87
71	.957504	71	.298283	71	293	47	35-15/87
72	.941756	72	.265796	72	297	55	51-63/87
73	.923705	73	.234530	73	302	4	8-24/87
74	.903445	74	.204649	74	306	12	24-72/87
75	.881081	75	.176307	75	310	20	41-33/87
76	.856731	76	.149652	76	314	28	57-81/87
77	.830520	77	.124825	77	318	37	14-42/87
78	.802587	78	.101953	78	322	45	31- 3/87
79	.773076	79	.081157	79	326	53	47-51/87
80	.742142	80	.062544	80	331	2	4-12/87
81	.709945	81	.046212	81	335	10	20-60/87
82	.676653	82	.032246	82	339	18	37-21/87
83	.642440	83	.020719	83	343	26	53-69/87
84	.607485	84	.011690	84	347	35	10-30/87
85	.571970	85	.005207	85	351	43	26-78/87
86	.536079	86	.001303	86	355	51	43-39/87
87	.500000	87	.000000	87	360	0	0

88 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

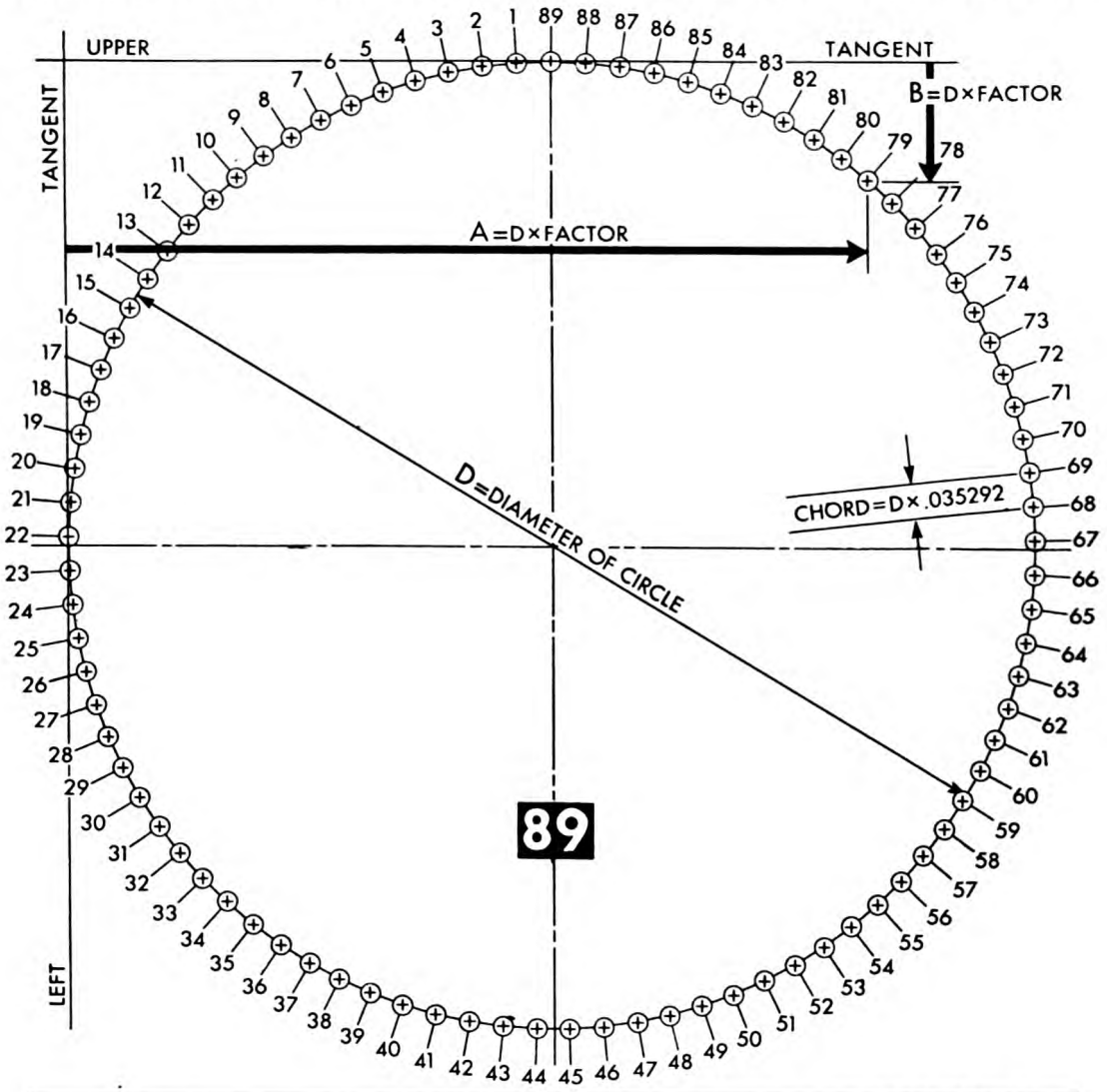


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.464330	1	.001274	1	4	5	27-24/88
2	.428843	2	.005089	2	8	10	54-48/88
3	.393717	3	.011427	3	12	16	21-72/88
4	.359134	4	.020254	4	16	21	49- 8/88
5	.325268	5	.031525	5	20	27	16-32/88
6	.292293	6	.045184	6	24	32	43-56/88
7	.260376	7	.061161	7	28	38	10-80/88
8	.229680	8	.079373	8	32	43	38-16/88
9	.200361	9	.099729	9	36	49	5-40/88
10	.172570	10	.122125	10	40	54	32-64/88
11	.146447	11	.146447	11	45	00	00000000
12	.122125	12	.172570	12	49	5	27-24/88
13	.099729	13	.200361	13	53	10	54-48/88
14	.079373	14	.229680	14	57	16	21-72/88
15	.061161	15	.260376	15	61	21	49- 8/88
16	.045184	16	.292293	16	65	27	16-32/88
17	.031525	17	.325268	17	69	32	43-56/88
18	.020254	18	.359134	18	73	38	10-80/88

COORDINATE FACTORS AND ANGLES—88 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
19	.011427	19	.393717	19	77	43	38-16/88
20	.005089	20	.428843	20	81	49	5-40/88
21	.001274	21	.464330	21	85	54	32-64/88
22	.000000	22	.500000	22	90	00	00000000
23	.001274	23	.535670	23	94	5	27-24/88
24	.005089	24	.571157	24	98	10	54-48/88
25	.011427	25	.606283	25	102	16	21-72/88
26	.020254	26	.640866	26	106	21	49- 8/88
27	.031525	27	.674732	27	110	27	16-32/88
28	.045184	28	.707708	28	114	32	43-56/88
29	.061161	29	.739624	29	118	38	10-80/88
30	.079373	30	.770320	30	122	43	38-16/88
31	.099729	31	.799639	31	126	49	5-40/88
32	.122125	32	.827430	32	130	54	32-64/88
33	.146447	33	.853553	33	135	00	00000000
34	.172570	34	.877875	34	139	5	27-24/88
35	.200361	35	.900271	35	143	10	54-48/88
36	.229680	36	.920627	36	147	16	21-72/88
37	.260376	37	.938839	37	151	21	49- 8/88
38	.292293	38	.954816	38	155	27	16-32/88
39	.325268	39	.968475	39	159	32	43-56/88
40	.359134	40	.979746	40	163	38	10-80/88
41	.393717	41	.988573	41	167	43	38-16/88
42	.428843	42	.994911	42	171	49	5-40/88
43	.464330	43	.998726	43	175	54	32-64/88
44	.500000	44	1.000000	44	180	00	00000000
45	.535670	45	.998726	45	184	5	27-24/88
46	.571157	46	.994911	46	188	10	54-48/88
47	.606283	47	.988573	47	192	16	21-72/88
48	.640866	48	.979746	48	196	21	49- 8/88
49	.674732	49	.968475	49	200	27	16-32/88
50	.707708	50	.954816	50	204	32	43-56/88
51	.739624	51	.938839	51	208	38	10-80/88
52	.770320	52	.920627	52	212	43	38-16/88
53	.799639	53	.900271	53	216	49	5-40/88
54	.827430	54	.877875	54	220	54	32-64/88
55	.853553	55	.853553	55	225	00	00000000
56	.877875	56	.827430	56	229	5	27-24/88
57	.900271	57	.799639	57	233	10	54-48/88
58	.920627	58	.770320	58	237	16	21-72/88
59	.938839	59	.739624	59	241	21	49- 8/88
60	.954816	60	.707708	60	245	27	16-32/88
61	.968475	61	.674732	61	249	32	43-56/88
62	.979746	62	.640866	62	253	38	10-80/88
63	.988573	63	.606283	63	257	43	38-16/88
64	.994911	64	.571157	64	261	49	5-40/88
65	.998726	65	.535670	65	265	54	32-64/88
66	1.000000	66	.500000	66	270	00	00000000
67	.998726	67	.464330	67	274	5	27-24/88
68	.994911	68	.428843	68	278	10	54-48/88
69	.988573	69	.393717	69	282	16	21-72/88
70	.979746	70	.359134	70	286	21	49- 8/88
71	.968475	71	.325268	71	290	27	16-32/88
72	.954816	72	.292293	72	294	32	43-56/88
73	.938839	73	.260376	73	298	38	10-80/88
74	.920627	74	.229680	74	302	43	38-16/88
75	.900271	75	.200361	75	306	49	5-40/88
76	.877875	76	.172570	76	310	54	32-64/88
77	.853553	77	.146447	77	315	00	00000000
78	.827430	78	.122125	78	319	5	27-24/88
79	.799639	79	.099729	79	323	10	54-48/88
80	.770320	80	.079373	80	327	16	21-72/88
81	.739624	81	.061161	81	331	21	49- 8/88
82	.707708	82	.045184	82	335	27	16-32/88
83	.674732	83	.031525	83	339	32	43-56/88
84	.640866	84	.020254	84	343	38	10-80/88
85	.606283	85	.011427	85	347	43	38-16/88
86	.571157	86	.005089	86	351	49	5-40/88
87	.535670	87	.001274	87	355	54	32-64/88
88	.500000	88	.000000	88	360	0	0

89 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

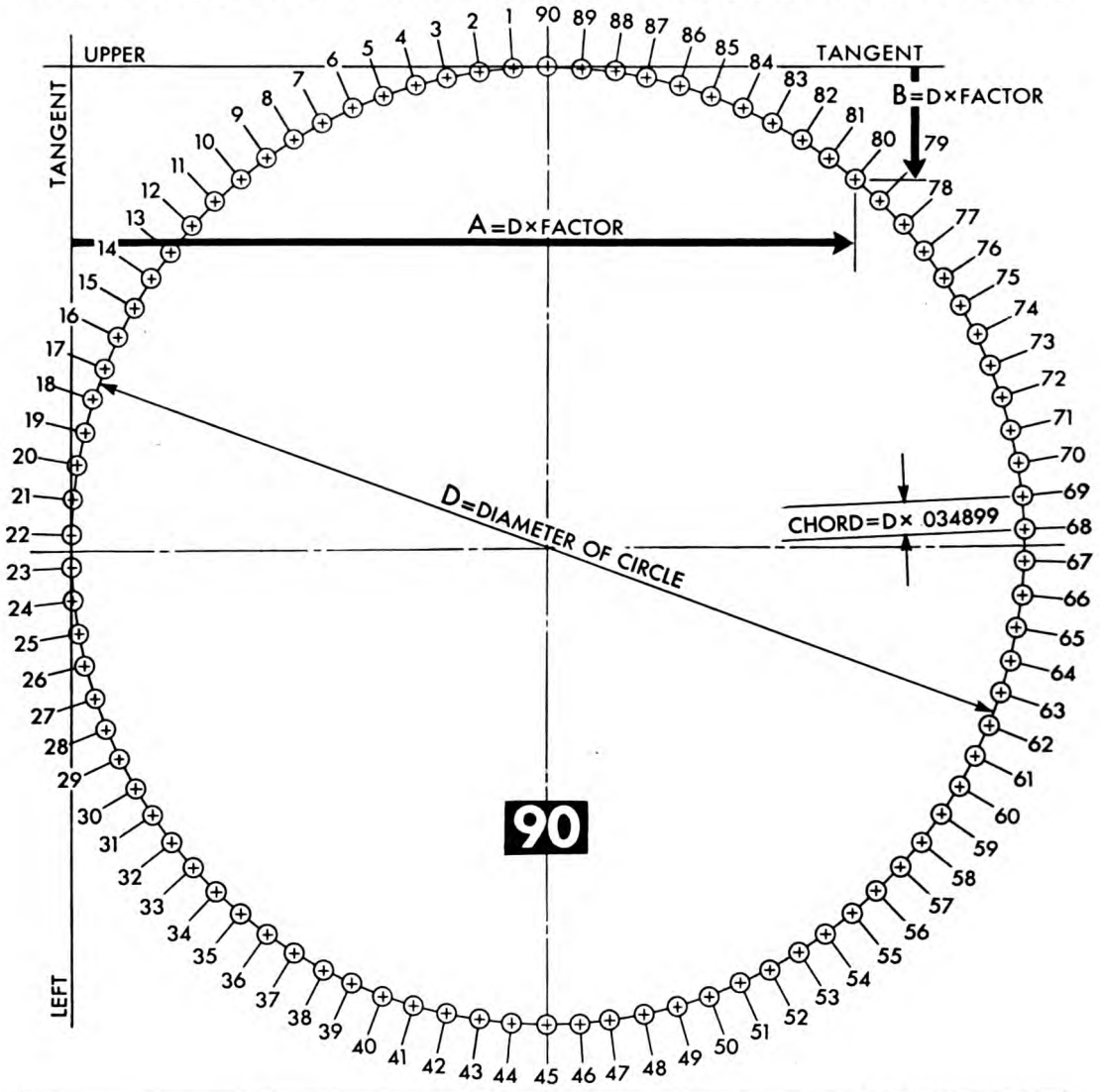


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.464731	1	.001245	1	4	2	41-71/89
2	.429637	2	.004976	2	8	5	23-53/89
3	.394894	3	.011172	3	12	8	5-35/89
4	.360674	4	.019804	4	16	10	47-17/89
5	.327148	5	.030828	5	20	13	28-88/89
6	.294484	6	.044190	6	24	16	10-70/89
7	.262844	7	.059822	7	28	18	52-52/89
8	.232385	8	.077647	8	32	21	34-34/89
9	.203259	9	.097576	9	36	24	16-16/89
10	.175612	10	.119511	10	40	26	57-87/89
11	.149580	11	.143340	11	44	29	39-69/89
12	.125295	12	.168947	12	48	32	21-51/89
13	.102876	13	.196203	13	52	35	3-33/89
14	.082436	14	.224972	14	56	37	45-15/89
15	.064076	15	.255112	15	60	40	26-86/89
16	.047888	16	.286472	16	64	43	8-68/89
17	.033952	17	.318896	17	68	45	50-50/89
18	.022338	18	.352221	18	72	48	32-32/89

COORDINATE FACTORS AND ANGLES—89 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
19	.013103	19	.386283	19	76	51	14-14/89
20	.006295	20	.420911	20	80	53	55-85/89
21	.001946	21	.455934	21	84	56	37-67/89
22	.000078	22	.491176	22	88	59	19-49/89
23	.000701	23	.526462	23	93	2	1-31/89
24	.003811	24	.561616	24	97	4	43-13/89
25	.009393	25	.596463	25	101	7	24-84/89
26	.017420	26	.630830	26	105	10	6-66/89
27	.027851	27	.664544	27	109	12	48-48/89
28	.040633	28	.697439	28	113	15	30-30/89
29	.055705	29	.729351	29	117	18	12-12/89
30	.072990	30	.760120	30	121	20	53-83/89
31	.092402	31	.789593	31	125	23	35-65/89
32	.113845	32	.817623	32	129	26	17-47/89
33	.137212	33	.844071	33	133	28	59-29/89
34	.162386	34	.868804	34	137	31	41-11/89
35	.189243	35	.891701	35	141	34	22-82/89
36	.217646	36	.912645	36	145	37	4-64/89
37	.247457	37	.931534	37	149	39	46-46/89
38	.278526	38	.948274	38	153	42	28-28/89
39	.310698	39	.962780	39	157	45	10-10/89
40	.343814	40	.974980	40	161	47	51-81/89
41	.377708	41	.984814	41	165	50	33-63/89
42	.412210	42	.992233	42	169	53	15-45/89
43	.447151	43	.997199	43	173	55	57-27/89
44	.482354	44	.999689	44	177	58	39- 9/89
45	.517646	45	.999689	45	182	1	20-80/89
46	.552849	46	.997199	46	186	4	2-62/89
47	.587790	47	.992233	47	190	6	44-44/89
48	.622292	48	.984814	48	194	9	26-26/89
49	.656186	49	.974980	49	198	12	8- 8/89
50	.689302	50	.962780	50	202	14	49-79/89
51	.721474	51	.948274	51	206	17	31-61/89
52	.752543	52	.931534	52	210	20	13-43/89
53	.782354	53	.912645	53	214	22	55-25/89
54	.810757	54	.891701	54	218	25	37- 7/89
55	.837614	55	.868804	55	222	28	18-78/89
56	.862788	56	.844071	56	226	31	00-60/89
57	.886155	57	.817623	57	230	33	42-42/89
58	.907598	58	.789593	58	234	36	24-24/89
59	.927010	59	.760120	59	238	39	6-6 /89
60	.944295	60	.729351	60	242	41	47-77/89
61	.959367	61	.697439	61	246	44	29-59/89
62	.972149	62	.664544	62	250	47	11-41/89
63	.982580	63	.630830	63	254	49	53-23/89
64	.990607	64	.596463	64	258	52	35- 5/89
65	.996189	65	.561616	65	262	55	16-76/89
66	.999299	66	.526462	66	266	57	58-58/89
67	.999922	67	.491176	67	271	00	40-40/89
68	.998054	68	.455934	68	275	3	22-22/89
69	.993705	69	.420911	69	279	6	4- 4/89
70	.986897	70	.386283	70	283	8	45-75/89
71	.977662	71	.352221	71	287	11	27-57/89
72	.966048	72	.318896	72	291	14	9-39/89
73	.952112	73	.286472	73	295	16	51-21/89
74	.935924	74	.255112	74	299	19	33- 3/89
75	.917564	75	.224972	75	303	22	14-74/89
76	.897124	76	.196203	76	307	24	56-56/89
77	.874705	77	.168947	77	311	27	38-38/89
78	.850420	78	.143340	78	315	30	20-20/89
79	.824388	79	.119511	79	319	33	2- 2/89
80	.796741	80	.097576	80	323	35	43-73/89
81	.767615	81	.077647	81	327	38	25-55/89
82	.737156	82	.059822	82	331	41	7-37/89
83	.705516	83	.044190	83	335	43	49-19/89
84	.672852	84	.030828	84	339	46	31- 1/89
85	.639326	85	.019804	85	343	49	12-72/89
86	.605106	86	.011172	86	347	51	54-54/89
87	.570363	87	.004976	87	351	54	36-36/89
88	.535269	88	.001245	88	355	57	18-18/89
89	.500000	89	.000000	89	360	0	0

90 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

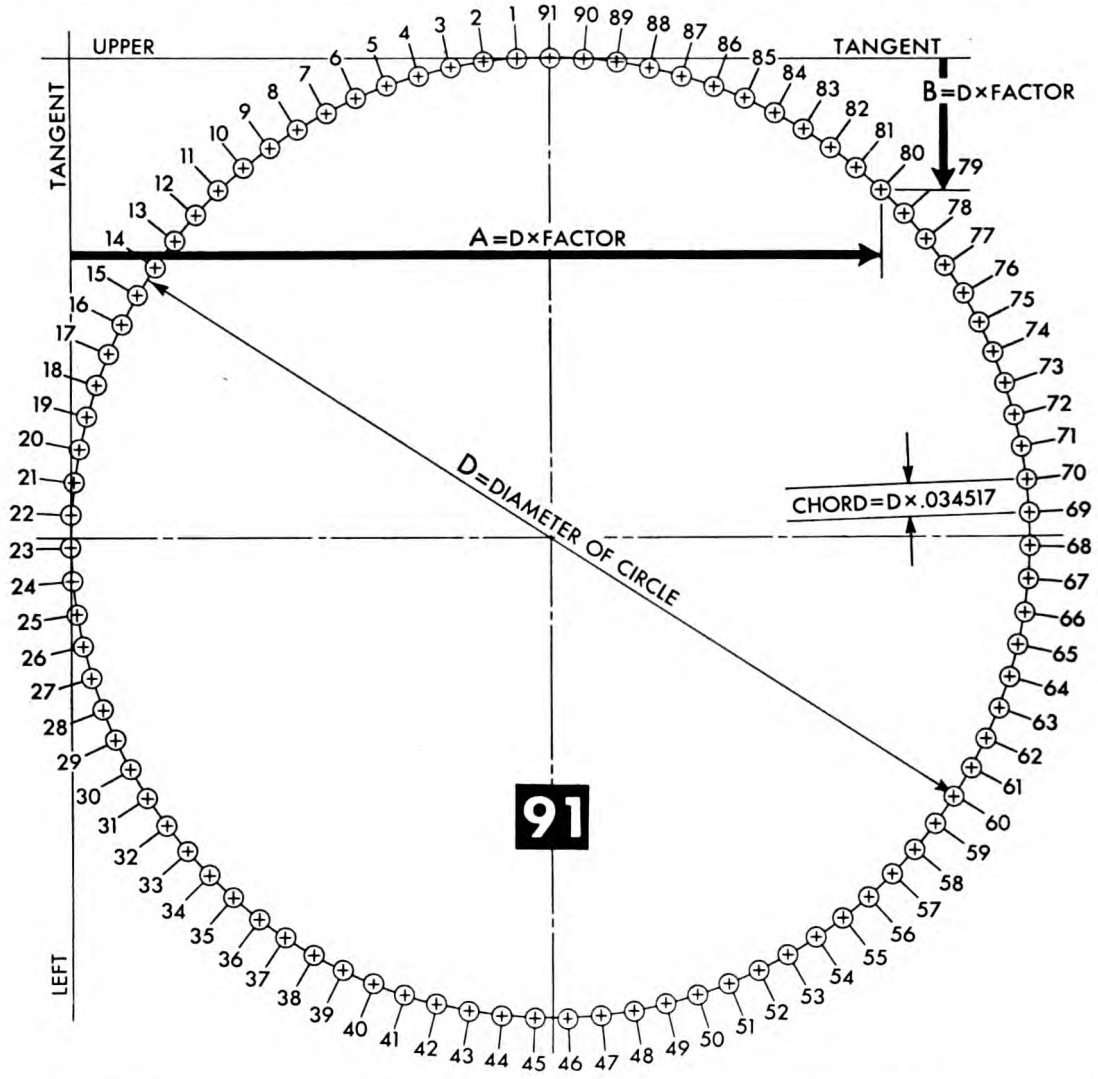


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.465122	1	.001218	4	0	0
2	.430413	2	.004866	8	0	0
3	.396044	3	.010926	12	0	0
4	.362181	4	.019369	16	0	0
5	.328990	5	.030154	20	0	0
6	.296632	6	.043227	24	0	0
7	.265264	7	.058526	28	0	0
8	.235040	8	.075976	32	0	0
9	.206107	9	.095492	36	0	0
10	.178606	10	.116978	40	0	0
11	.152671	11	.140330	44	0	0
12	.128428	12	.165435	48	0	0
13	.105995	13	.192169	52	0	0
14	.085481	14	.220404	56	0	0
15	.066987	15	.250000	60	0	0
16	.050603	16	.280814	64	0	0
17	.036408	17	.312697	68	0	0
18	.024472	18	.345492	72	0	0

COORDINATE FACTORS AND ANGLES—90 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
19	.014852	19	.379039	19	76	0	0
20	.007596	20	.413176	20	80	0	0
21	.002739	21	.447736	21	84	0	0
22	.000305	22	.482550	22	88	0	0
23	.000305	23	.517450	23	92	0	0
24	.002739	24	.552264	24	96	0	0
25	.007596	25	.586824	25	100	0	0
26	.014852	26	.620961	26	104	0	0
27	.024472	27	.654508	27	108	0	0
28	.036408	28	.687303	28	112	0	0
29	.050603	29	.719186	29	116	0	0
30	.066987	30	.750000	30	120	0	0
31	.085481	31	.779596	31	124	0	0
32	.105995	32	.807831	32	128	0	0
33	.128428	33	.834565	33	132	0	0
34	.152671	34	.859670	34	136	0	0
35	.178606	35	.883022	35	140	0	0
36	.206107	36	.904508	36	144	0	0
37	.235040	37	.924024	37	148	0	0
38	.265264	38	.941474	38	152	0	0
39	.296632	39	.956773	39	156	0	0
40	.328990	40	.969846	40	160	0	0
41	.362181	41	.980631	41	164	0	0
42	.396044	42	.989074	42	168	0	0
43	.430413	43	.995134	43	172	0	0
44	.465122	44	.998782	44	176	0	0
45	.500000	45	1.000000	45	180	0	0
46	.534878	46	.998782	46	184	0	0
47	.569587	47	.995134	47	188	0	0
48	.603956	48	.989074	48	192	0	0
49	.637819	49	.980631	49	196	0	0
50	.671010	50	.969846	50	200	0	0
51	.703368	51	.956773	51	204	0	0
52	.734736	52	.941474	52	208	0	0
53	.764960	53	.924024	53	212	0	0
54	.793893	54	.904508	54	216	0	0
55	.821394	55	.883022	55	220	0	0
56	.847329	56	.859670	56	224	0	0
57	.871572	57	.834565	57	228	0	0
58	.894005	58	.807831	58	232	0	0
59	.914519	59	.779596	59	236	0	0
60	.933013	60	.750000	60	240	0	0
61	.949397	61	.719186	61	244	0	0
62	.963592	62	.687303	62	248	0	0
63	.975528	63	.654508	63	252	0	0
64	.985148	64	.620961	64	256	0	0
65	.992404	65	.586824	65	260	0	0
66	.997261	66	.552264	66	264	0	0
67	.999695	67	.517450	67	268	0	0
68	.999695	68	.482550	68	272	0	0
69	.997261	69	.447736	69	276	0	0
70	.992404	70	.413176	70	280	0	0
71	.985148	71	.379039	71	284	0	0
72	.975528	72	.345492	72	288	0	0
73	.963592	73	.312697	73	292	0	0
74	.949397	74	.280814	74	296	0	0
75	.933013	75	.250000	75	300	0	0
76	.914519	76	.220404	76	304	0	0
77	.894005	77	.192169	77	308	0	0
78	.871572	78	.165435	78	312	0	0
79	.847329	79	.140330	79	316	0	0
80	.821394	80	.116978	80	320	0	0
81	.793893	81	.095492	81	324	0	0
82	.764960	82	.075976	82	328	0	0
83	.734736	83	.058526	83	332	0	0
84	.703368	84	.043227	84	336	0	0
85	.671010	85	.030154	85	340	0	0
86	.637819	86	.019369	86	344	0	0
87	.603956	87	.010926	87	348	0	0
88	.569587	88	.004866	88	352	0	0
89	.534878	89	.001218	89	356	0	0
90	.500000	90	.000000	90	360	0	0

91 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

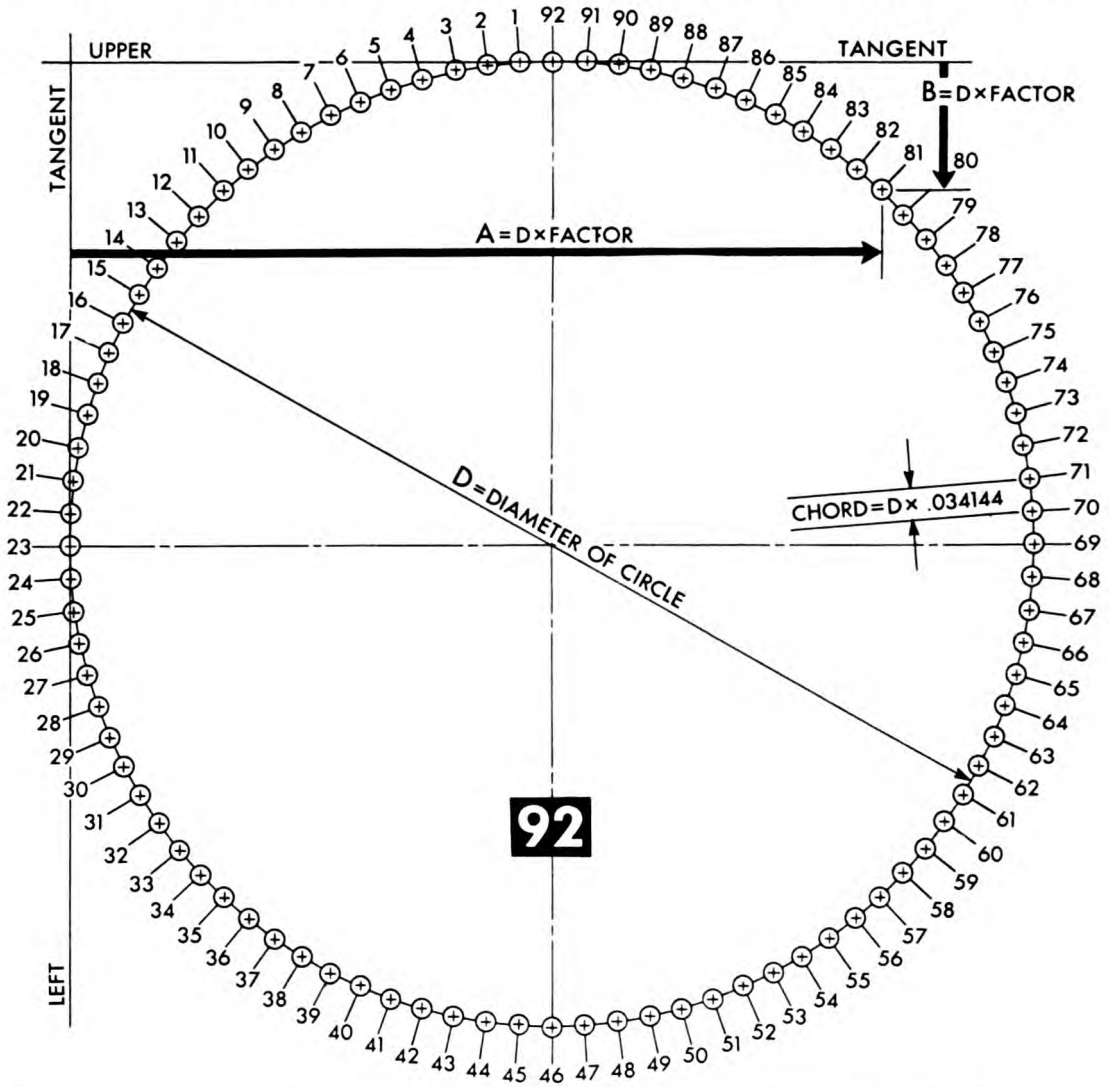


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.465504	1	.001192	1	3	57	21-69/91
2	.431173	2	.004759	2	7	54	43-47/91
3	.397171	3	.010688	3	11	52	5-25/91
4	.363657	4	.018948	4	15	49	27- 3/91
5	.330793	5	.029501	5	19	46	48-72/91
6	.298737	6	.042296	6	23	44	10-50/91
7	.267638	7	.057272	7	27	41	32-28/91
8	.237648	8	.074358	8	31	38	54- 6/91
9	.208907	9	.093472	9	35	36	15-75/91
10	.181554	10	.114523	10	39	33	37-53/91
11	.155718	11	.137412	11	43	30	59-31/91
12	.131523	12	.162028	12	47	28	21- 9/91
13	.109084	13	.188255	13	51	25	42-78/91
14	.088508	14	.215968	14	55	23	4-56/91
15	.069893	15	.245034	15	59	20	26-34/91
16	.053327	16	.275315	16	63	17	48-12/91
17	.038890	17	.306667	17	67	15	9-81/91
18	.026651	18	.338940	18	71	12	31-59/91

COORDINATE FACTORS AND ANGLES—91 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
19	.016667	19	.371980	19	75	9	53-37/91
20	.008986	20	.405631	20	79	7	15-15/91
21	.003646	21	.439732	21	83	4	36-84/91
22	.000670	22	.474119	22	87	1	58-62/91
23	.000074	23	.508630	23	90	59	20-40/91
24	.001861	24	.543100	24	94	56	42-18/91
25	.006022	25	.577365	25	98	54	3-87/91
26	.012536	26	.611260	26	102	51	25-65/91
27	.021374	27	.644626	27	106	48	47-43/91
28	.032492	28	.677302	28	110	46	9-21/91
29	.045838	29	.709134	29	114	43	30-90/91
30	.061349	30	.739969	30	118	40	52-68/91
31	.078950	31	.769660	31	122	38	14-46/91
32	.098557	32	.798066	32	126	35	36-24/91
33	.120077	33	.825052	33	130	32	58- 2/91
34	.143408	34	.850489	34	134	30	19-71/91
35	.168439	35	.874255	35	138	27	41-49/91
36	.195049	36	.896238	36	142	25	3-27/91
37	.223113	37	.916333	37	146	22	25- 5/91
38	.252496	38	.934444	38	150	19	46-74/91
39	.283058	39	.950484	39	154	17	8-52/91
40	.314655	40	.964378	40	158	14	30-30/91
41	.347134	41	.976059	41	162	11	52- 8/91
42	.380342	42	.985471	42	166	9	13-77/91
43	.414120	43	.992569	43	170	6	35-55/91
44	.448308	44	.997321	44	174	3	57-33/91
45	.482742	45	.999702	45	178	1	19-11/91
46	.517258	46	.999702	46	181	58	40-80/91
47	.551692	47	.997321	47	185	56	2-58/91
48	.585880	48	.992569	48	189	53	24-36/91
49	.619658	49	.985471	49	193	50	46-14/91
50	.652866	50	.976059	50	197	48	7-83/91
51	.685346	51	.964378	51	201	45	29-61/91
52	.716942	52	.950484	52	205	42	51-39/91
53	.747504	53	.934444	53	209	40	13-17/91
54	.776887	54	.916333	54	213	37	34-86/91
55	.804951	55	.896238	55	217	34	56-64/91
56	.831561	56	.874255	56	221	32	18-42/91
57	.856592	57	.850489	57	225	29	40-20/91
58	.879923	58	.825052	58	229	27	1-89/91
59	.901443	59	.798066	59	233	24	23-67/91
60	.921050	60	.769660	60	237	21	45-45/91
61	.938651	61	.739969	61	241	19	7-23/91
62	.954162	62	.709134	62	245	16	29- 1/91
63	.967508	63	.677302	63	249	13	50-70/91
64	.978626	64	.644626	64	253	11	12-48/91
65	.987464	65	.611260	65	257	8	34-26/91
66	.993978	66	.577365	66	261	5	56- 4/91
67	.998139	67	.543100	67	265	3	17-73/91
68	.999926	68	.508630	68	269	00	39-51/91
69	.999330	69	.474119	69	272	58	1-29/91
70	.996354	70	.439732	70	276	55	23- 7/91
71	.991014	71	.405631	71	280	52	44-76/91
72	.983333	72	.371980	72	284	50	6-54/91
73	.973349	73	.338940	73	288	47	28-32/91
74	.961110	74	.306667	74	292	44	50-10/91
75	.946673	75	.275315	75	296	42	11-79/91
76	.930107	76	.245034	76	300	39	33-57/91
77	.911492	77	.215968	77	304	36	55-35/91
78	.890916	78	.188255	78	308	34	17-13/91
79	.868477	79	.162028	79	312	31	38-82/91
80	.844282	80	.137412	80	316	29	00-60/91
81	.818446	81	.114523	81	320	26	22-38/91
82	.791093	82	.093472	82	324	23	44-16/91
83	.762352	83	.074358	83	328	21	5-85/91
84	.732362	84	.057272	84	332	18	27-63/91
85	.701263	85	.042296	85	336	15	49-41/91
86	.669207	86	.029501	86	340	13	11-19/91
87	.636343	87	.018948	87	344	10	32-88/91
88	.602829	88	.010688	88	348	7	54-66/91
89	.568827	89	.004759	89	352	5	16-44/91
90	.534496	90	.001192	90	356	2	38-22/91
91	.500000	91	.000000	91	360	0	0

92 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

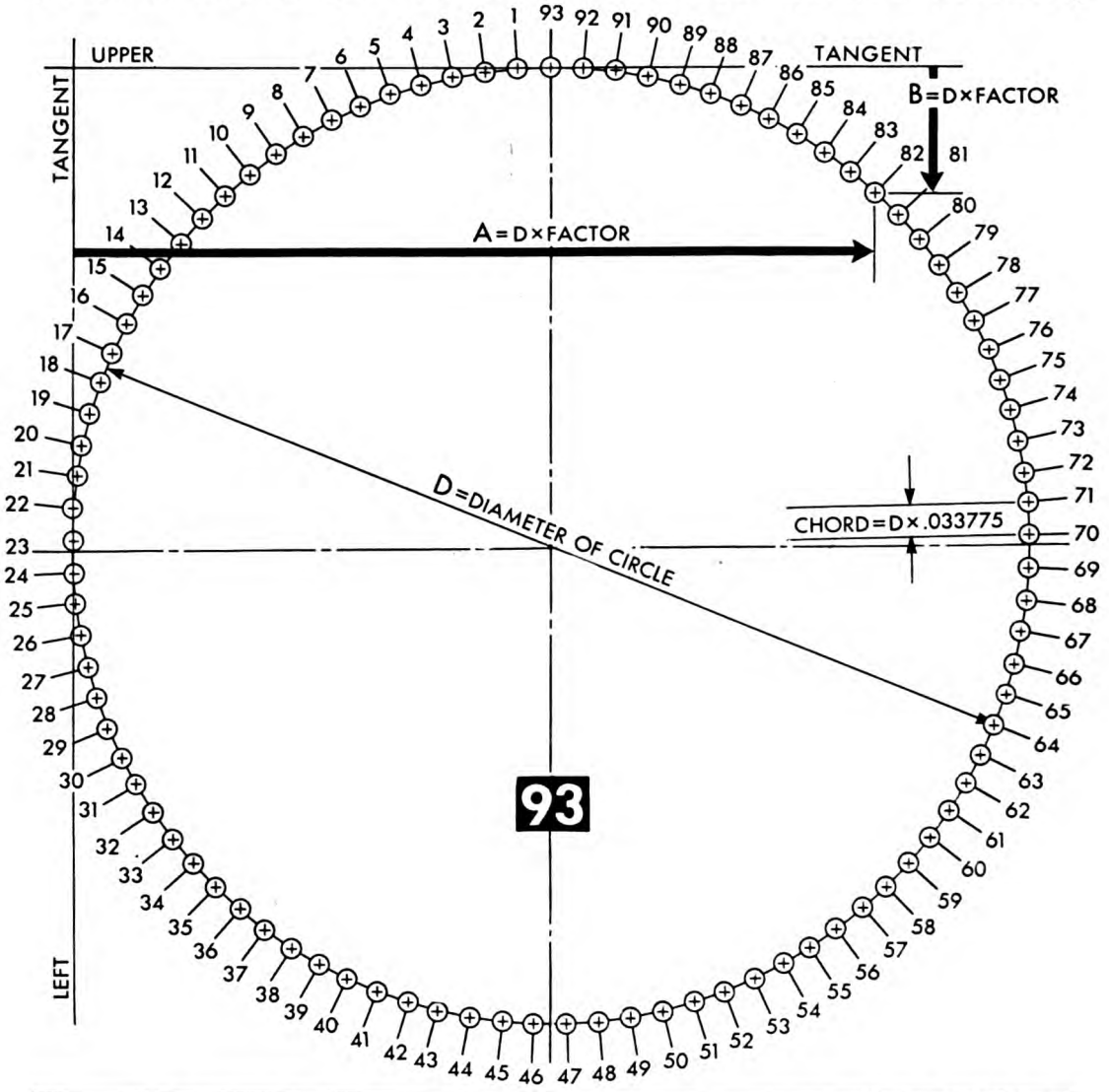


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.465879	1	.001166	1	3	54	46–88/92
2	.431917	2	.004657	2	7	49	33–84/92
3	.398272	3	.010458	3	11	44	20–80/92
4	.365102	4	.018541	4	15	39	7–76/92
5	.332560	5	.028870	5	19	33	54–72/92
6	.300803	6	.041394	6	23	28	41–68/92
7	.269967	7	.056057	7	27	23	28–64/92
8	.240208	8	.072790	8	31	18	15–60/92
9	.211660	9	.091515	9	35	13	2–56/92
10	.184456	10	.112144	10	39	7	49–52/92
11	.158723	11	.134582	11	43	2	36–48/92
12	.134582	12	.158723	12	46	57	23–44/92
13	.112144	13	.184456	13	50	52	10–40/92
14	.091515	14	.211660	14	54	46	57–36/92
15	.072790	15	.240208	15	58	41	44–32/92
16	.056057	16	.269967	16	62	36	31–28/92
17	.041394	17	.300803	17	66	31	18–24/92
18	.028870	18	.332560	18	70	26	5–20/92
19	.018541	19	.365102	19	74	20	52–16/92

COORDINATE FACTORS AND ANGLES—92 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
20	.010458	20	.398272	20	78	15	39-12/92
21	.004657	21	.431917	21	82	10	26- 8/92
22	.001166	22	.465879	22	86	5	13- 4/92
23	.000000	23	.500000	23	90	00	00000000
24	.001166	24	.534121	24	93	54	46-88/92
25	.004657	25	.568083	25	97	49	33-84/92
26	.010458	26	.601728	26	101	44	20-80/92
27	.018541	27	.634898	27	105	39	7-76/92
28	.028870	28	.667440	28	109	33	54-72/92
29	.041394	29	.699197	29	113	28	41-68/92
30	.056057	30	.730033	30	117	23	28-64/92
31	.072790	31	.759792	31	121	18	15-60/92
32	.091515	32	.788340	32	125	13	2-56/92
33	.112144	33	.815544	33	129	7	49-52/92
34	.134582	34	.841277	34	133	2	36-48/92
35	.158723	35	.865418	35	136	57	23-44/92
36	.184456	36	.887856	36	140	52	10-40/92
37	.211660	37	.908485	37	144	46	57-36/92
38	.240208	38	.927210	38	148	41	44-32/92
39	.269967	39	.943943	39	152	36	31-28/92
40	.300803	40	.958606	40	156	31	18-24/92
41	.332560	41	.971130	41	160	26	5-20/92
42	.365102	42	.981459	42	164	20	52-16/92
43	.398272	43	.989542	43	168	15	39-12/92
44	.431917	44	.995343	44	172	10	26- 8/92
45	.465879	45	.998834	45	176	5	13- 4/92
46	.500000	46	1.000000	46	180	00	00000000
47	.534121	47	.998834	47	183	54	46-88/92
48	.568083	48	.995343	48	187	49	33-84/92
49	.601728	49	.989542	49	191	44	20-80/92
50	.634898	50	.981459	50	195	39	7-76/92
51	.667440	51	.971130	51	199	33	54-72/92
52	.699197	52	.958606	52	203	28	41-68/92
53	.730033	53	.943943	53	207	23	28-64/92
54	.759792	54	.927210	54	211	18	15-60/92
55	.788340	55	.908485	55	215	13	2-56/92
56	.815544	56	.887856	56	219	7	49-52/92
57	.841277	57	.865418	57	223	2	36-48/92
58	.865418	58	.841277	58	226	57	23-44/92
59	.887856	59	.815544	59	230	52	10-40/92
60	.908485	60	.788340	60	234	46	57-36/92
61	.927210	61	.759792	61	238	41	44-32/92
62	.943943	62	.730033	62	242	36	31-28/92
63	.958606	63	.699197	63	246	31	18-24/92
64	.971130	64	.667440	64	250	26	5-20/92
65	.981459	65	.634898	65	254	20	52-16/92
66	.989542	66	.601728	66	258	15	39-12/92
67	.995343	67	.568083	67	262	10	26- 8/92
68	.998834	68	.534121	68	266	5	13- 4/92
69	1.000000	69	.500000	69	270	00	00000000
70	.998834	70	.465879	70	273	54	46-88/92
71	.995343	71	.431917	71	277	49	33-84/92
72	.989542	72	.398272	72	281	44	20-80/92
73	.981459	73	.365102	73	285	39	7-76/92
74	.971130	74	.332560	74	289	33	54-72/92
75	.958606	75	.300803	75	293	28	41-68/92
76	.943943	76	.269967	76	297	23	28-64/92
77	.927210	77	.240208	77	301	18	15-60/92
78	.908485	78	.211660	78	305	13	2-56/92
79	.887856	79	.184456	79	309	7	49-52/92
80	.865418	80	.158723	80	313	2	36-48/92
81	.841277	81	.134582	81	316	57	23-44/92
82	.815544	82	.112144	82	320	52	10-40/92
83	.788340	83	.091515	83	324	46	57-36/92
84	.759792	84	.072790	84	328	41	44-32/92
85	.730033	85	.056057	85	332	36	31-28/92
86	.699197	86	.041394	86	336	31	18-24/92
87	.667440	87	.028870	87	340	26	5-20/92
88	.634898	88	.018541	88	344	20	52-16/92
89	.601728	89	.010458	89	348	15	39-12/92
90	.568083	90	.004657	90	352	10	26- 8/92
91	.534121	91	.001166	91	356	5	13- 4/92
92	.500000	92	.000000	92	360	0	0

93 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

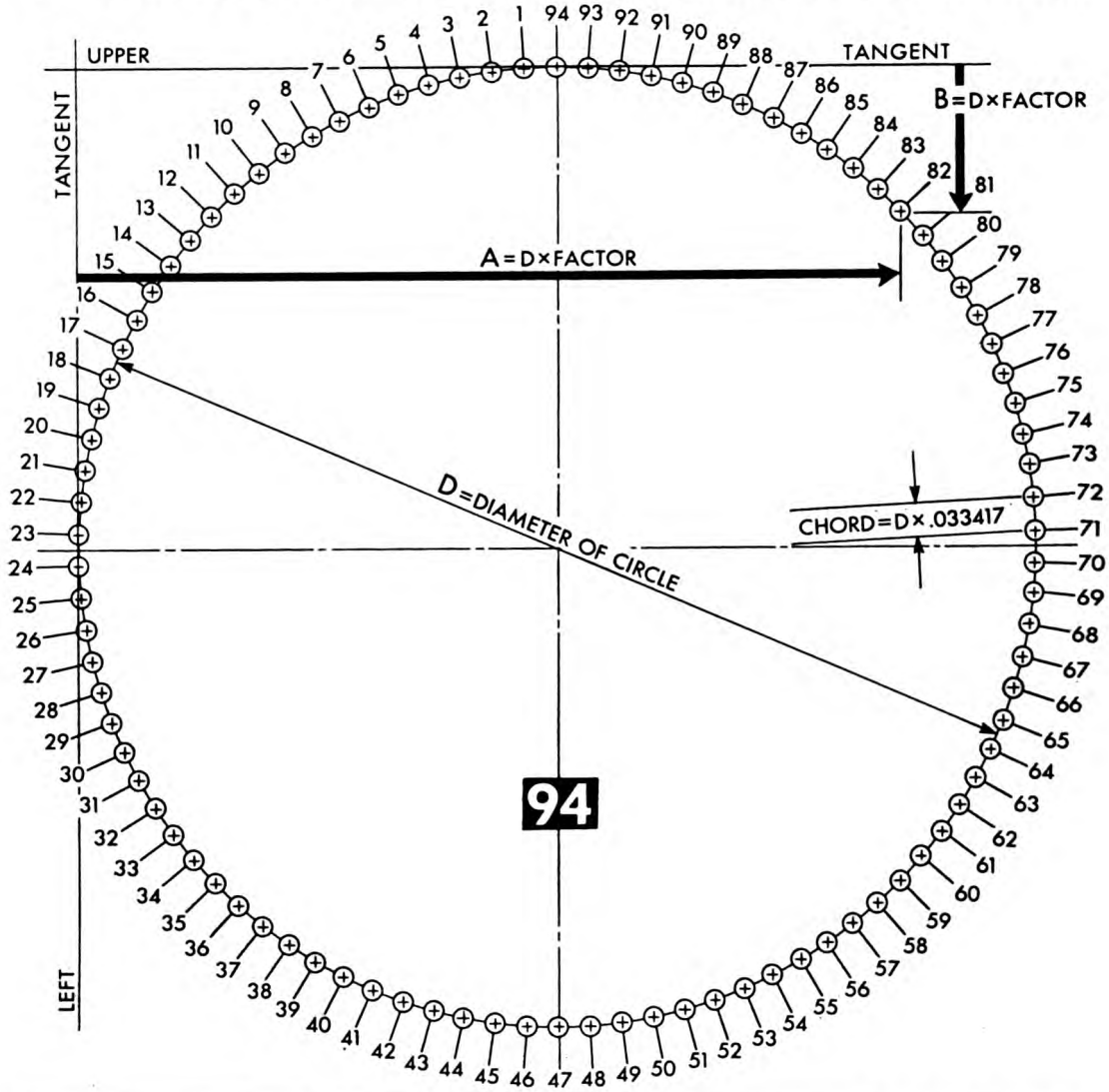


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.466245	1	.001141	1	3	52	15–45/93
2	.432644	2	.004558	2	7	44	30–90/93
3	.399351	3	.010235	3	11	36	46–42/93
4	.366516	4	.018147	4	15	29	1–87/93
5	.334291	5	.028258	5	19	21	17–39/93
6	.302822	6	.040521	6	23	13	32–84/93
7	.272253	7	.054881	7	27	5	48–36/93
8	.242722	8	.071271	8	30	58	3–81/93
9	.214366	9	.089618	9	34	50	19–33/93
10	.187313	10	.109838	10	38	42	34–78/93
11	.161686	11	.131837	11	42	34	50–30/93
12	.137604	12	.155517	12	46	27	5–75/93
13	.115174	13	.180768	13	50	19	21–27/93
14	.094501	14	.207476	14	54	11	36–72/93
15	.075678	15	.235518	15	58	3	52–24/93
16	.058791	16	.264767	16	61	56	7–69/93
17	.043917	17	.295090	17	65	48	23–21/93
18	.031124	18	.326347	18	69	40	38–66/93
19	.020470	19	.358397	19	73	32	54–18/93

COORDINATE FACTORS AND ANGLES—93 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
20	.012005	20	.391093	20	77	25	9-63/93
21	.005766	21	.424286	21	81	17	25-15/93
22	.001782	22	.457824	22	85	9	40-60/93
23	.000071	23	.491555	23	89	1	56-12/93
24	.000642	24	.525325	24	92	54	11-57/93
25	.003491	25	.558978	25	96	46	27- 9/93
26	.008605	26	.592363	26	100	38	42-54/93
27	.015961	27	.625326	27	104	30	58- 6/93
28	.025526	28	.657718	28	108	23	13-51/93
29	.037256	29	.689389	29	112	15	29- 3/93
30	.051098	30	.720197	30	116	7	44-48/93
31	.066987	31	.750000	31	120	00	00000000
32	.084853	32	.778662	32	123	52	15-45/93
33	.104612	33	.806053	33	127	44	30-90/93
34	.126176	34	.832047	34	131	36	46-42/93
35	.149445	35	.856527	35	135	29	1-87/93
36	.174314	36	.879379	36	139	21	17-39/93
37	.200669	37	.900500	37	143	13	32-84/93
38	.228389	38	.919795	38	147	5	48-36/93
39	.257349	39	.937173	39	150	58	3-81/93
40	.287416	40	.952557	40	154	50	19-33/93
41	.318453	41	.965876	41	158	42	34-78/93
42	.350319	42	.977070	42	162	34	50-30/93
43	.382867	43	.986086	43	166	27	5-75/93
44	.415950	44	.992885	44	170	19	21-27/93
45	.449416	45	.997435	45	174	11	36-72/93
46	.483113	46	.999715	46	178	3	52-24/93
47	.516887	47	.999715	47	181	56	7-69/93
48	.550584	48	.997435	48	185	48	23-21/93
49	.584050	49	.992885	49	189	40	38-66/93
50	.617133	50	.986086	50	193	32	54-18/93
51	.649682	51	.977070	51	197	25	9-63/93
52	.681547	52	.965876	52	201	17	25-15/93
53	.712584	53	.952557	53	205	9	40-60/93
54	.742651	54	.937173	54	209	1	56-12/93
55	.771611	55	.919795	55	212	54	11-57/93
56	.799331	56	.900500	56	216	46	27- 9/93
57	.825686	57	.879379	57	220	38	42-54/93
58	.850555	58	.856527	58	224	30	58- 6/93
59	.873824	59	.832047	59	228	23	13-51/93
60	.895388	60	.806053	60	232	15	29- 3/93
61	.915147	61	.778662	61	236	7	44-48/93
62	.933013	62	.750000	62	240	00	00000000
63	.948902	63	.720197	63	243	52	15-45/93
64	.962744	64	.689389	64	247	44	30-90/93
65	.974474	65	.657718	65	251	36	46-42/93
66	.984039	66	.625326	66	255	29	1-87/93
67	.991395	67	.592363	67	259	21	17-39/93
68	.996509	68	.558978	68	263	13	32-84/93
69	.999358	69	.525325	69	267	5	48-36/93
70	.999929	70	.491555	70	270	58	3-81/93
71	.998218	71	.457824	71	274	50	19-33/93
72	.994234	72	.424286	72	278	42	34-78/93
73	.987995	73	.391093	73	282	34	50-30/93
74	.979530	74	.358397	74	286	27	5-75/93
75	.968876	75	.326347	75	290	19	21-27/93
76	.956083	76	.295090	76	294	11	36-72/93
77	.941209	77	.264767	77	298	3	52-24/93
78	.924322	78	.235518	78	301	56	7-69/93
79	.905499	79	.207476	79	305	48	23-21/93
80	.884826	80	.180768	80	309	40	38-66/93
81	.862396	81	.155517	81	313	32	54-18/93
82	.838314	82	.131837	82	317	25	9-63/93
83	.812687	83	.109838	83	321	17	25-15/93
84	.785634	84	.089618	84	325	9	40-60/93
85	.757278	85	.071271	85	329	1	56-12/93
86	.727747	86	.054881	86	332	54	11-57/93
87	.697178	87	.040521	87	336	46	27- 9/93
88	.665709	88	.028258	88	340	38	42-54/93
89	.633484	89	.018147	89	344	30	58- 6/93
90	.600649	90	.010235	90	348	23	13-51/93
91	.567356	91	.004558	91	352	15	29- 3/93
92	.533755	92	.001141	92	356	7	44-48/93
93	.500000	93	.000000	93	360	0	0

94 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

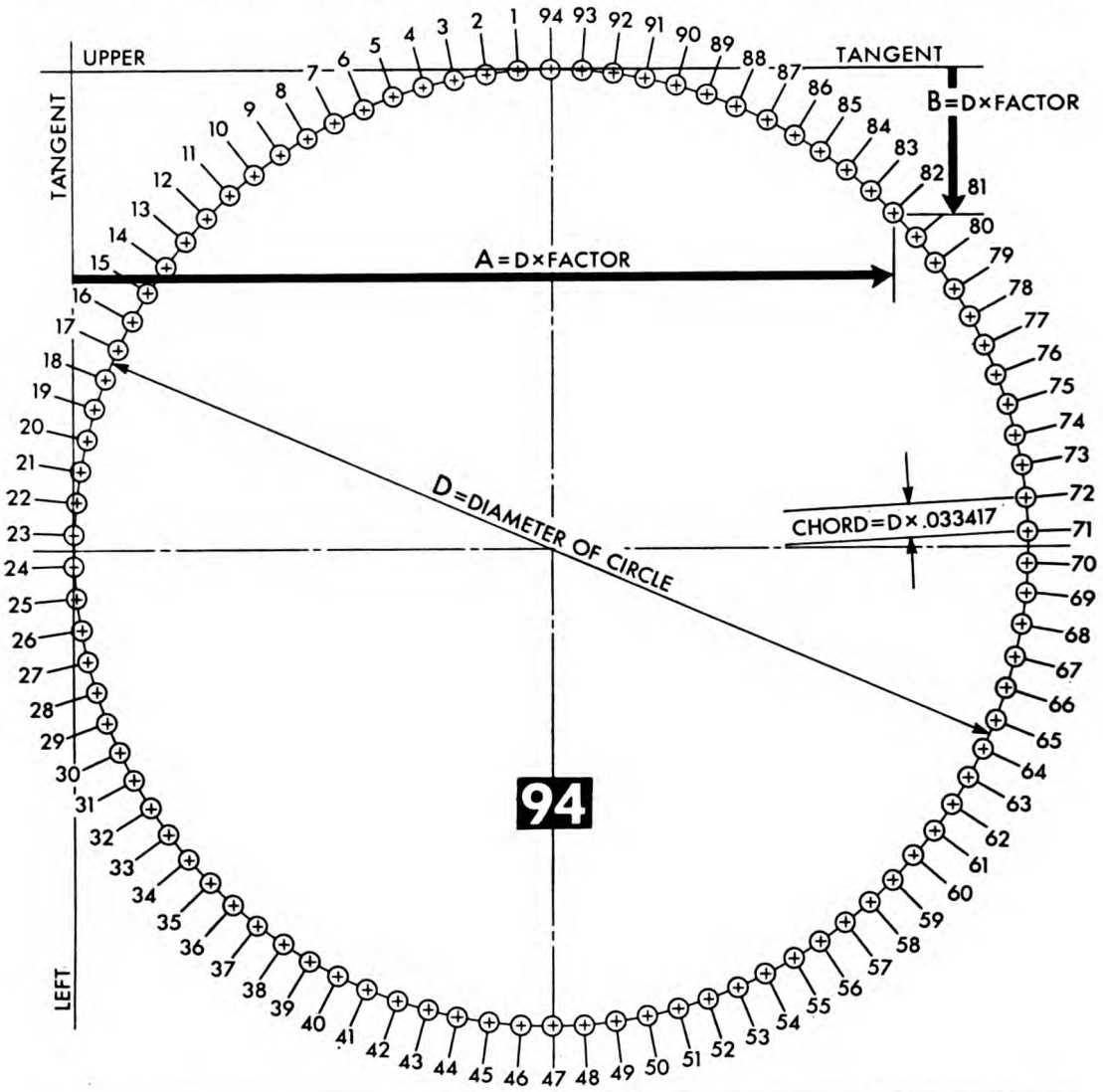


	FACTOR FOR "A"		FACTOR FOR "B"		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.466604	1	.001117	1	3	49	47–22/94
2	.433357	2	.004461	2	7	39	34–44/94
3	.400407	3	.010019	3	11	29	21–66/94
4	.367902	4	.017765	4	15	19	8–88/94
5	.335988	5	.027665	5	19	8	56–16/94
6	.304806	6	.039675	6	22	58	43–38/94
7	.274495	7	.053741	7	26	48	30–60/94
8	.245192	8	.069799	8	30	38	17–82/94
9	.217026	9	.087779	9	34	28	5–10/94
10	.190125	10	.107600	10	38	17	52–32/94
11	.164608	11	.129174	11	42	7	39–54/94
12	.140588	12	.152404	12	45	57	26–76/94
13	.118174	13	.177186	13	49	47	14– 4/94
14	.097465	14	.203410	14	53	37	1–26/94
15	.078554	15	.230959	15	57	26	48–48/94
16	.061525	16	.259709	16	61	16	35–70/94
17	.046455	17	.289532	17	65	6	22–92/94
18	.033410	18	.320296	18	68	56	10–20/94
19	.022449	19	.351862	19	72	45	57–42/94

COORDINATE FACTORS AND ANGLES—94 HOLE DIVISION

	→ FACTOR FOR "A"	FACTOR FOR "B" ↓		ANGLE OF HOLE		
				DEG.	MIN.	SEC.
20	.013621	20	.384090	20	76	35	44-64/94
21	.006965	21	.416835	21	80	25	31-86/94
22	.002511	22	.449952	22	84	15	19-14/94
23	.000279	23	.483293	23	88	5	6-36/94
24	.000279	24	.516707	24	91	54	53-58/94
25	.002511	25	.550048	25	95	44	40-80/94
26	.006965	26	.583165	26	99	34	28- 8/94
27	.013621	27	.615910	27	103	24	15-30/94
28	.022449	28	.648138	28	107	14	2-52/94
29	.033410	29	.679704	29	111	3	49-74/94
30	.046455	30	.710468	30	114	53	37- 2/94
31	.061525	31	.740291	31	118	43	24-24/94
32	.078554	32	.769041	32	122	33	11-46/94
33	.097465	33	.796590	33	126	22	58-68/94
34	.118174	34	.822814	34	130	12	45-90/94
35	.140588	35	.847596	35	134	2	33-18/94
36	.164608	36	.870826	36	137	52	20-40/94
37	.190125	37	.892400	37	141	42	7-62/94
38	.217026	38	.912221	38	145	31	54-84/94
39	.245192	39	.930201	39	149	21	42-12/94
40	.274495	40	.946259	40	153	11	29-34/94
41	.304806	41	.960325	41	157	1	16-56/94
42	.335988	42	.972335	42	160	51	3-78/94
43	.367902	43	.982235	43	164	40	51- 6/94
44	.400407	44	.989981	44	168	30	38-28/94
45	.433357	45	.995539	45	172	20	25-50/94
46	.466604	46	.998883	46	176	10	12-72/94
47	.500000	47	1.000000	47	180	00	00000000
48	.533396	48	.998883	48	183	49	47-22/94
49	.566643	49	.995539	49	187	39	34-44/94
50	.599593	50	.989981	50	191	29	21-66/94
51	.632098	51	.982235	51	195	19	8-88/94
52	.664012	52	.972335	52	199	8	56-16/94
53	.695194	53	.960325	53	202	58	43-38/94
54	.725505	54	.946259	54	206	48	30-60/94
55	.754808	55	.930201	55	210	38	17-82/94
56	.782974	56	.912221	56	214	28	5-10/94
57	.809875	57	.892400	57	218	17	52-32/94
58	.835392	58	.870826	58	222	7	39-54/94
59	.859412	59	.847596	59	225	57	26-76/94
60	.881826	60	.822814	60	229	47	14- 4/94
61	.902535	61	.796590	61	233	37	1-26/94
62	.921446	62	.769041	62	237	26	48-48/94
63	.938475	63	.740291	63	241	16	35-70/94
64	.953545	64	.710468	64	245	6	22-92/94
65	.966590	65	.679704	65	248	56	10-20/94
66	.977551	66	.648138	66	252	45	57-42/94
67	.986379	67	.615910	67	256	35	44-64/94
68	.993035	68	.583165	68	260	25	31-86/94
69	.997489	69	.550048	69	264	15	19-14/94
70	.999721	70	.516707	70	268	5	6-36/94
71	.999721	71	.483293	71	271	54	53-58/94
72	.997489	72	.449952	72	275	44	40-80/94
73	.993035	73	.416835	73	279	34	28- 8/94
74	.986379	74	.384090	74	283	24	15-30/94
75	.977551	75	.351862	75	287	14	2-52/94
76	.966590	76	.320296	76	291	3	49-74/94
77	.953545	77	.289532	77	294	53	37- 2/94
78	.938475	78	.259709	78	298	43	24-24/94
79	.921446	79	.230959	79	302	33	11-46/94
80	.902535	80	.203410	80	306	22	58-68/94
81	.881826	81	.177186	81	310	12	45-90/94
82	.859412	82	.152404	82	314	2	33-18/94
83	.835392	83	.129174	83	317	52	20-40/94
84	.809875	84	.107600	84	321	42	7-62/94
85	.782974	85	.087779	85	325	31	54-84/94
86	.754808	86	.069799	86	329	21	42-12/94
87	.725505	87	.053741	87	333	11	29-34/94
88	.695194	88	.039675	88	337	1	16-56/94
89	.664012	89	.027665	89	340	51	3-78/94
90	.632098	90	.017765	90	344	40	51- 6/94
91	.599593	91	.010019	91	348	30	38-28/94
92	.566643	92	.004461	92	352	20	25-50/94
93	.533396	93	.001117	93	356	10	12-72/94
94	.500000	94	.000000	94	360	0	0

94 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

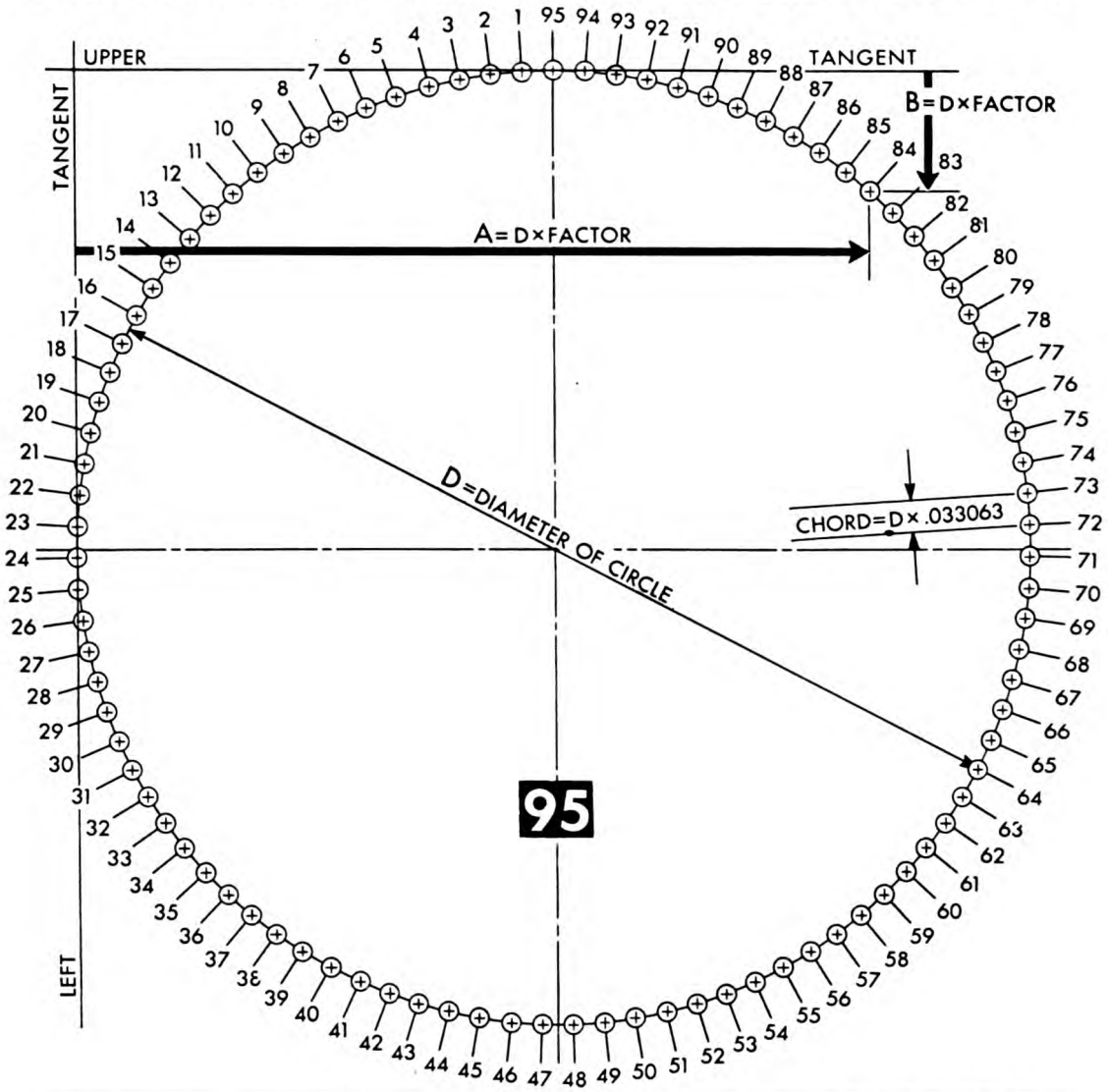


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE		
					DEG.	MIN.	SEC.
1	.466604	1	.001117	1	3	49	47–22/94
2	.433357	2	.004461	2	7	39	34–44/94
3	.400407	3	.010019	3	11	29	21–66/94
4	.367902	4	.017765	4	15	19	8–88/94
5	.335988	5	.027665	5	19	8	56–16/94
6	.304806	6	.039675	6	22	58	43–38/94
7	.274495	7	.053741	7	26	48	30–60/94
8	.245192	8	.069799	8	30	38	17–82/94
9	.217026	9	.087779	9	34	28	5–10/94
10	.190125	10	.107600	10	38	17	52–32/94
11	.164608	11	.129174	11	42	7	39–54/94
12	.140588	12	.152404	12	45	57	26–76/94
13	.118174	13	.177186	13	49	47	14– 4/94
14	.097465	14	.203410	14	53	37	1–26/94
15	.078554	15	.230959	15	57	26	48–48/94
16	.061525	16	.259709	16	61	16	35–70/94
17	.046455	17	.289532	17	65	6	22–92/94
18	.033410	18	.320296	18	68	56	10–20/94
19	.022449	19	.351862	19	72	45	57–42/94

COORDINATE FACTORS AND ANGLES—94 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
20	.013621	20	.384090	20	76	35	44-64/94
21	.006965	21	.416835	21	80	25	31-86/94
22	.002511	22	.449952	22	84	15	19-14/94
23	.000279	23	.483293	23	88	5	6-36/94
24	.000279	24	.516707	24	91	54	53-58/94
25	.002511	25	.550048	25	95	44	40-80/94
26	.006965	26	.583165	26	99	34	28- 8/94
27	.013621	27	.615910	27	103	24	15-30/94
28	.022449	28	.648138	28	107	14	2-52/94
29	.033410	29	.679704	29	111	3	49-74/94
30	.046455	30	.710468	30	114	53	37- 2/94
31	.061525	31	.740291	31	118	43	24-24/94
32	.078554	32	.769041	32	122	33	11-46/94
33	.097465	33	.796590	33	126	22	58-68/94
34	.118174	34	.822814	34	130	12	45-90/94
35	.140588	35	.847596	35	134	2	33-18/94
36	.164608	36	.870826	36	137	52	20-40/94
37	.190125	37	.892400	37	141	42	7-62/94
38	.217026	38	.912221	38	145	31	54-84/94
39	.245192	39	.930201	39	149	21	42-12/94
40	.274495	40	.946259	40	153	11	29-34/94
41	.304806	41	.960325	41	157	1	16-56/94
42	.335988	42	.972335	42	160	51	3-78/94
43	.367902	43	.982235	43	164	40	51- 6/94
44	.400407	44	.989981	44	168	30	38-28/94
45	.433357	45	.995539	45	172	20	25-50/94
46	.466604	46	.998883	46	176	10	12-72/94
47	.500000	47	1.000000	47	180	00	00000000
48	.533396	48	.998883	48	183	49	47-22/94
49	.566643	49	.995539	49	187	39	34-44/94
50	.599593	50	.989981	50	191	29	21-66/94
51	.632098	51	.982235	51	195	19	8-88/94
52	.664012	52	.972335	52	199	8	56-16/94
53	.695194	53	.960325	53	202	58	43-38/94
54	.725505	54	.946259	54	206	48	30-60/94
55	.754808	55	.930201	55	210	38	17-82/94
56	.782974	56	.912221	56	214	28	5-10/94
57	.809875	57	.892400	57	218	17	52-32/94
58	.835392	58	.870826	58	222	7	39-54/94
59	.859412	59	.847596	59	225	57	26-76/94
60	.881826	60	.822814	60	229	47	14- 4/94
61	.902535	61	.796590	61	233	37	1-26/94
62	.921446	62	.769041	62	237	26	48-48/94
63	.938475	63	.740291	63	241	16	35-70/94
64	.953545	64	.710468	64	245	6	22-92/94
65	.966590	65	.679704	65	248	56	10-20/94
66	.977551	66	.648138	66	252	45	57-42/94
67	.986379	67	.615910	67	256	35	44-64/94
68	.993035	68	.583165	68	260	25	31-86/94
69	.997489	69	.550048	69	264	15	19-14/94
70	.999721	70	.516707	70	268	5	6-36/94
71	.999721	71	.483293	71	271	54	53-58/94
72	.997489	72	.449952	72	275	44	40-80/94
73	.993035	73	.416835	73	279	34	28- 8/94
74	.986379	74	.384090	74	283	24	15-30/94
75	.977551	75	.351862	75	287	14	2-52/94
76	.966590	76	.320296	76	291	3	49-74/94
77	.953545	77	.289532	77	294	53	37- 2/94
78	.938475	78	.259709	78	298	43	24-24/94
79	.921446	79	.230959	79	302	33	11-46/94
80	.902535	80	.203410	80	306	22	58-68/94
81	.881826	81	.177186	81	310	12	45-90/94
82	.859412	82	.152404	82	314	2	33-18/94
83	.835392	83	.129174	83	317	52	20-40/94
84	.809875	84	.107600	84	321	42	7-62/94
85	.782974	85	.087779	85	325	31	54-84/94
86	.754808	86	.069799	86	329	21	42-12/94
87	.725505	87	.053741	87	333	11	29-34/94
88	.695194	88	.039675	88	337	1	16-56/94
89	.664012	89	.027665	89	340	51	3-78/94
90	.632098	90	.017765	90	344	40	51- 6/94
91	.599593	91	.010019	91	348	30	38-28/94
92	.566643	92	.004461	92	352	20	25-50/94
93	.533396	93	.001117	93	356	10	12-72/94
94	.500000	94	.000000	94	360	0	0

95 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

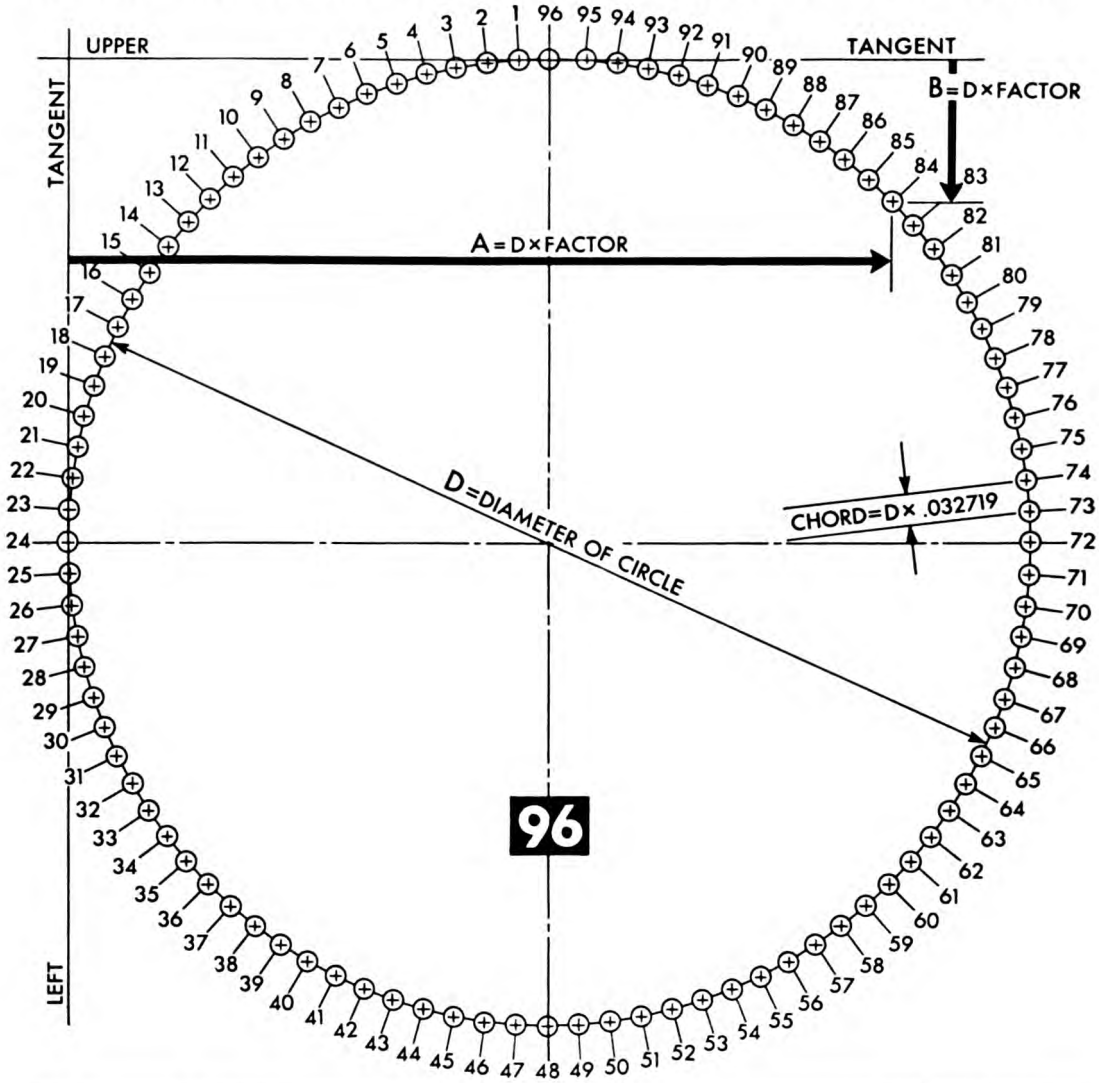


➡	FACTOR FOR "A"	FACTOR FOR "B"	⬇	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.466955	1	.001093	1	3	47	22-19/95
2	.434054	2	.004368	2	7	34	44-20/95
3	.401441	3	.009810	3	11	22	6-30/95
4	.369260	4	.017396	4	15	9	28-40/95
5	.337650	5	.027091	5	18	56	50-50/95
6	.306750	6	.038855	6	22	44	12-60/95
7	.276696	7	.052635	7	26	31	34-70/95
8	.247617	8	.068372	8	30	18	56-80/95
9	.219643	9	.085996	9	34	6	18-90/95
10	.192894	10	.105430	10	37	53	41- 5/95
11	.167488	11	.126589	11	41	41	3-15/95
12	.143536	12	.149382	12	45	28	25-25/95
13	.121143	13	.173706	13	49	15	47-35/95
14	.100406	14	.199459	14	53	3	9-45/95
15	.081417	15	.226526	15	56	50	31-55/95
16	.064258	16	.254788	16	60	37	53-65/95
17	.049004	17	.284123	17	64	25	15-75/95
18	.035723	18	.314401	18	68	12	37-85/95
19	.024472	19	.345492	19	72	00	00000000

COORDINATE FACTORS AND ANGLES—95 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
20	.015300	20	.377257	20	75	47	22–10/95
21	.008247	21	.409560	21	79	34	44–20/95
22	.003345	22	.442258	22	83	22	6–30/95
23	.000615	23	.475208	23	87	9	28–40/95
24	.000068	24	.508267	24	90	56	50–50/95
25	.001708	25	.541290	25	94	44	12–60/95
26	.005526	26	.574132	26	98	31	34–70/95
27	.011507	27	.606650	27	102	18	56–80/95
28	.019623	28	.638701	28	106	6	18–90/95
29	.029840	29	.670147	29	109	53	41– 5/95
30	.042113	30	.700848	30	113	41	3–15/95
31	.056389	31	.730671	31	117	28	25–25/95
32	.072604	32	.759485	32	121	15	47–35/95
33	.090688	33	.787164	33	125	3	9–45/95
34	.110561	34	.813588	34	128	50	31–55/95
35	.132138	35	.838641	35	132	37	53–65/95
36	.155323	36	.862213	36	136	25	15–75/95
37	.180016	37	.884201	37	140	12	37–85/95
38	.206107	38	.904508	38	144	00	00000000
39	.233484	39	.923048	39	147	47	22–10/95
40	.262026	40	.939737	40	151	34	44–20/95
41	.291609	41	.954503	41	155	22	6–30/95
42	.322103	42	.967282	42	159	9	28–40/95
43	.353375	43	.978018	43	162	56	50–50/95
44	.385289	44	.986663	44	166	44	12–60/95
45	.417702	45	.993181	45	170	31	34–70/95
46	.450478	46	.997541	46	174	18	56–80/95
47	.483468	47	.999727	47	178	6	18–90/95
48	.516532	48	.999727	48	181	53	41– 5/95
49	.549522	49	.997541	49	185	41	3–15/95
50	.582298	50	.993181	50	189	28	25–25/95
51	.614712	51	.986663	51	193	15	47–35/95
52	.646625	52	.978018	52	197	3	9–45/95
53	.677897	53	.967282	53	200	50	31–55/95
54	.708391	54	.954503	54	204	37	53–65/95
55	.737974	55	.939737	55	208	25	15–75/95
56	.766516	56	.923048	56	212	12	37–85/95
57	.793893	57	.904508	57	216	00	00000000
58	.819984	58	.884201	58	219	47	22–10/95
59	.844677	59	.862213	59	223	34	44–20/95
60	.867862	60	.838641	60	227	22	6–30/95
61	.889439	61	.813588	61	231	9	28–40/95
62	.909312	62	.787164	62	234	56	50–50/95
63	.927396	63	.759485	63	238	44	12–60/95
64	.943611	64	.730671	64	242	31	34–70/95
65	.957887	65	.700848	65	246	18	56–80/95
66	.970160	66	.670147	66	250	6	18–90/95
67	.980377	67	.638701	67	253	53	41– 5/95
68	.988493	68	.606650	68	257	41	3–15/95
69	.994474	69	.574132	69	261	28	25–25/95
70	.998292	70	.541290	70	265	15	47–35/95
71	.999932	71	.508267	71	269	3	9–45/95
72	.999385	72	.475208	72	272	50	31–55/95
73	.996655	73	.442258	73	276	37	53–65/95
74	.991753	74	.409560	74	280	25	15–75/95
75	.984700	75	.377257	75	284	12	37–85/95
76	.975528	76	.345492	76	288	00	00000000
77	.964277	77	.314401	77	291	47	22–10/95
78	.950996	78	.284123	78	295	34	44–20/95
79	.935742	79	.254788	79	299	22	6–30/95
80	.918583	80	.226526	80	303	9	28–40/95
81	.899594	81	.199459	81	306	56	50–50/95
82	.878857	82	.173706	82	310	44	12–60/95
83	.856464	83	.149382	83	314	31	34–70/95
84	.832512	84	.126589	84	318	18	56–80/95
85	.807106	85	.105430	85	322	6	18–90/95
86	.780358	86	.085996	86	325	53	41– 5/95
87	.752383	87	.068372	87	329	41	3–15/95
88	.723304	88	.052635	88	333	28	25–25/95
89	.693250	89	.038855	89	337	15	47–35/95
90	.662350	90	.027091	90	341	3	9–45/95
91	.630740	91	.017396	91	344	50	31–55/95
92	.598559	92	.009810	92	348	37	53–65/95
93	.565946	93	.004368	93	352	25	15–75/95
94	.533045	94	.001093	94	356	12	37–85/95
95	.500000	95	.000000	95	360	0	0

96 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

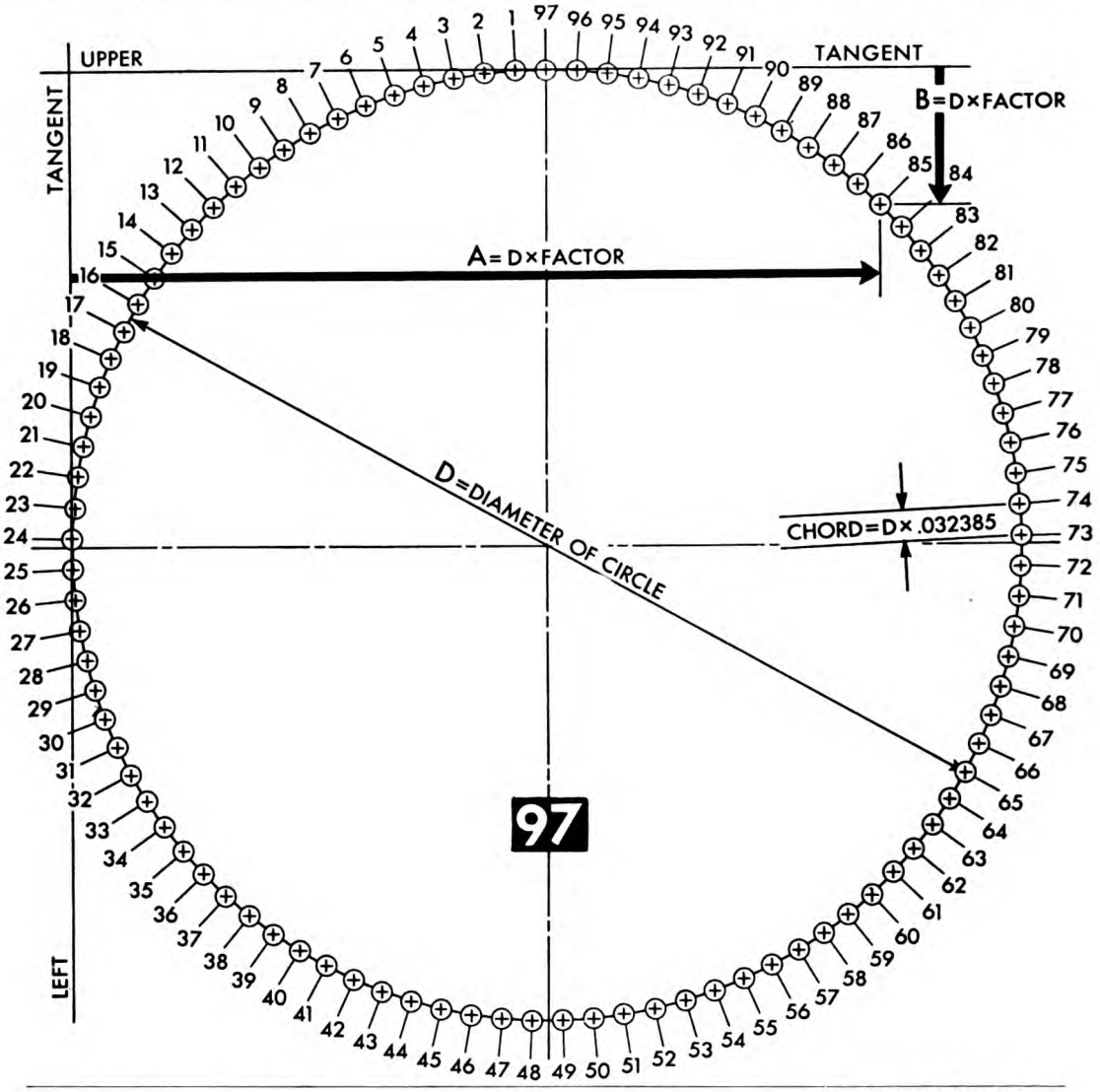


→	FACTOR FOR "A"	FACTOR FOR "B"	↓		ANGLE OF HOLE DEG.	MIN.	SEC.
1	.467298	1	.001071	1	3	45	0
2	.434737	2	.004278	2	7	30	0
3	.402455	3	.009607	3	11	15	0
4	.370590	4	.017037	4	15	00	0
5	.339280	5	.026535	5	18	45	0
6	.308658	6	.038060	6	22	30	0
7	.278856	7	.051564	7	26	15	0
8	.250000	8	.066987	8	30	00	0
9	.222215	9	.084265	9	33	45	0
10	.195619	10	.103323	10	37	30	0
11	.170327	11	.124080	11	41	15	0
12	.146447	12	.146447	12	45	00	0
13	.124080	13	.170327	13	48	45	0
14	.103323	14	.195619	14	52	30	0
15	.084265	15	.222215	15	56	15	0
16	.066987	16	.250000	16	60	00	0
17	.051564	17	.278856	17	63	45	0
18	.038060	18	.308658	18	67	30	0
19	.026535	19	.339280	19	71	15	0
20	.017037	20	.370590	20	75	00	0

COORDINATE FACTORS AND ANGLES—96 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
21	.009607	21	.402455	21	78	45	0
22	.004278	22	.434737	22	82	30	0
23	.001071	23	.467298	23	86	15	0
24	.000000	24	.500000	24	90	00	0
25	.001071	25	.532702	25	93	45	0
26	.004278	26	.565263	26	97	30	0
27	.009607	27	.597545	27	101	15	0
28	.017037	28	.629410	28	105	00	0
29	.026535	29	.660720	29	108	45	0
30	.038060	30	.691342	30	112	30	0
31	.051564	31	.721144	31	116	15	0
32	.066987	32	.750000	32	120	00	0
33	.084265	33	.777785	33	123	45	0
34	.103323	34	.804381	34	127	30	0
35	.124080	35	.829673	35	131	15	0
36	.146447	36	.853553	36	135	00	0
37	.170327	37	.875920	37	138	45	0
38	.195619	38	.896677	38	142	30	0
39	.222215	39	.915735	39	146	15	0
40	.250000	40	.933013	40	150	00	0
41	.278856	41	.948436	41	153	45	0
42	.308658	42	.961940	42	157	30	0
43	.339280	43	.973465	43	161	15	0
44	.370590	44	.982963	44	165	00	0
45	.402455	45	.990393	45	168	45	0
46	.434737	46	.995722	46	172	30	0
47	.467298	47	.998929	47	176	15	0
48	.500000	48	1.000000	48	180	00	0
49	.532702	49	.998929	49	183	45	0
50	.565263	50	.995722	50	187	30	0
51	.597545	51	.990393	51	191	15	0
52	.629410	52	.982963	52	195	00	0
53	.660720	53	.973465	53	198	45	0
54	.691342	54	.961940	54	202	30	0
55	.721144	55	.948436	55	206	15	0
56	.750000	56	.933013	56	210	00	0
57	.777785	57	.915735	57	213	45	0
58	.804381	58	.896677	58	217	30	0
59	.829673	59	.875920	59	221	15	0
60	.853553	60	.853553	60	225	00	0
61	.875920	61	.829673	61	228	45	0
62	.896677	62	.804381	62	232	30	0
63	.915735	63	.777785	63	236	15	0
64	.933013	64	.750000	64	240	00	0
65	.948436	65	.721144	65	243	45	0
66	.961940	66	.691342	66	247	30	0
67	.973465	67	.660720	67	251	15	0
68	.982963	68	.629410	68	255	00	0
69	.990393	69	.597545	69	258	45	0
70	.995722	70	.565263	70	262	30	0
71	.998929	71	.532702	71	266	15	0
72	1.000000	72	.500000	72	270	00	0
73	.998929	73	.467298	73	273	45	0
74	.995722	74	.434737	74	277	30	0
75	.990393	75	.402455	75	281	15	0
76	.982963	76	.370590	76	285	00	0
77	.973465	77	.339280	77	288	45	0
78	.961940	78	.308658	78	292	30	0
79	.948436	79	.278856	79	296	15	0
80	.933013	80	.250000	80	300	00	0
81	.915735	81	.222215	81	303	45	0
82	.896677	82	.195619	82	307	30	0
83	.875920	83	.170327	83	311	15	0
84	.853553	84	.146447	84	315	00	0
85	.829673	85	.124080	85	318	45	0
86	.804381	86	.103323	86	322	30	0
87	.777785	87	.084265	87	326	15	0
88	.750000	88	.066987	88	330	00	0
89	.721144	89	.051564	89	333	45	0
90	.691342	90	.038060	90	337	30	0
91	.660720	91	.026535	91	341	15	0
92	.629410	92	.017037	92	345	00	0
93	.597545	93	.009607	93	348	45	0
94	.565263	94	.004278	94	352	30	0
95	.532702	95	.001071	95	356	15	0
96	.500000	96	.000000	96	360	0	0

97 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

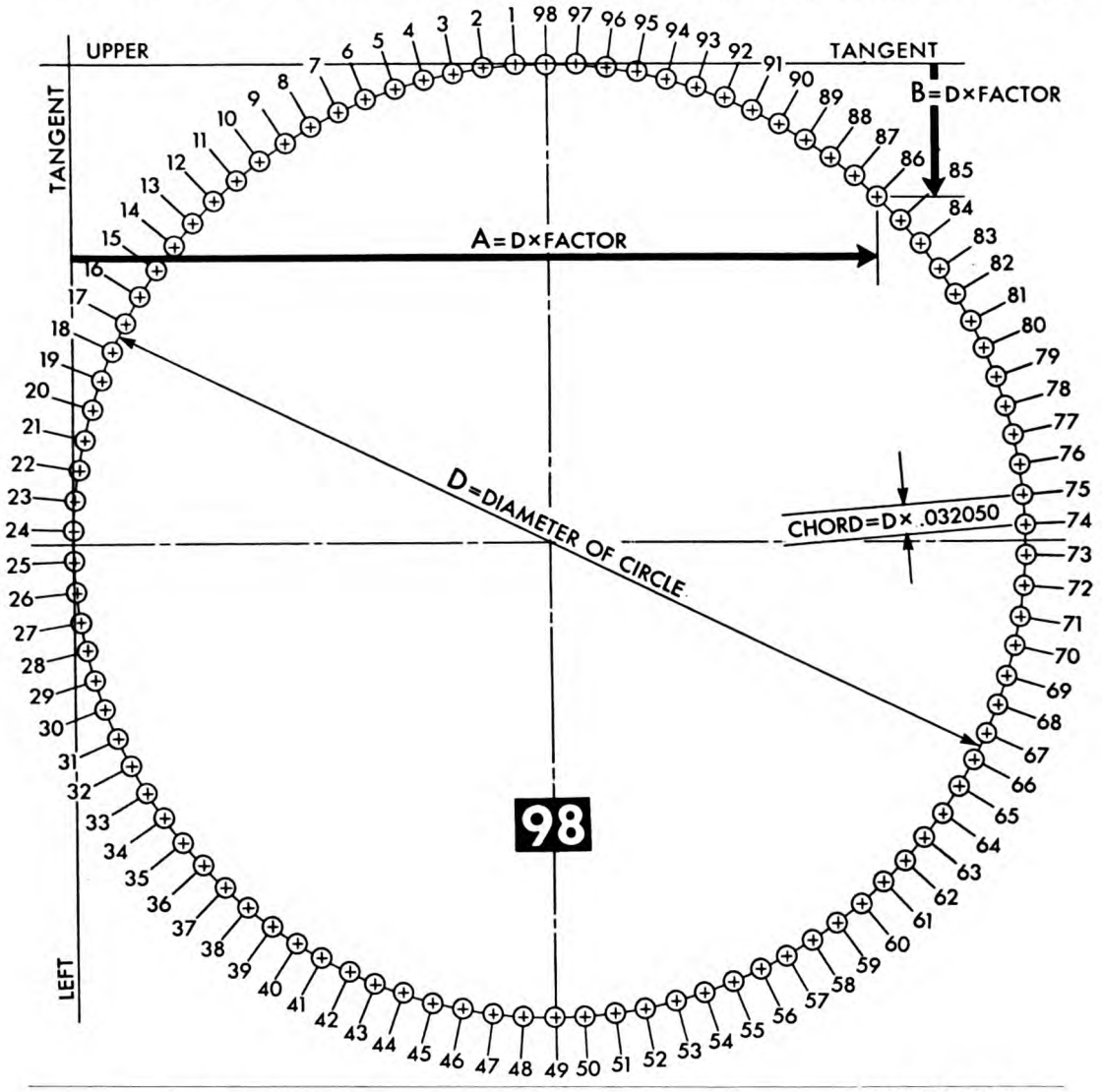


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.467635	1	.001049	1	3	42	40–80/97
2	.435406	2	.004190	2	7	25	21–63/97
3	.403448	3	.009411	3	11	8	2–46/97
4	.371894	4	.016690	4	14	50	43–29/97
5	.340879	5	.025995	5	18	33	24–12/97
6	.310530	6	.037289	6	22	16	4–92/97
7	.280976	7	.050524	7	25	58	45–75/97
8	.252341	8	.065644	8	29	41	26–58/97
9	.224745	9	.082586	9	33	24	7–41/97
10	.198303	10	.101278	10	37	6	48–24/97
11	.173126	11	.121644	11	40	49	29– 7/97
12	.149321	12	.143596	12	44	32	9–87/97
13	.126986	13	.167042	13	48	14	50–70/97
14	.106216	14	.191886	14	51	57	31–53/97
15	.087098	15	.218021	15	55	40	12–36/97
16	.969711	16	.245340	16	59	22	53–19/97
17	.054130	17	.273726	17	63	5	34– 2/97
18	.040418	18	.303062	18	66	48	14–82/97
19	.028634	19	.333224	19	70	30	55–65/97
20	.018827	20	.364085	20	74	13	36–48/97

COORDINATE FACTORS AND ANGLES—97 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
21	.011039	21	.395516	21	77	56	17-31/97
22	.005301	22	.427386	22	81	38	58-14/97
23	.001638	23	.459560	23	85	21	38-94/97
24	.000066	24	.491903	24	89	4	19-77/97
25	.000590	25	.524281	25	92	47	00-60/97
26	.003209	26	.556557	26	96	29	41-43/97
27	.007912	27	.588596	27	100	12	22-26/97
28	.014679	28	.620262	28	103	55	3- 9/97
29	.023481	29	.651425	29	107	37	43-89/97
30	.034282	30	.681952	30	111	20	24-72/97
31	.047036	31	.711717	31	115	3	5-55/97
32	.061691	32	.740593	32	118	45	46-38/97
33	.078183	33	.768460	33	122	28	27-21/97
34	.096445	34	.795201	34	126	11	8- 4/97
35	.116400	35	.820704	35	129	53	48-84/97
36	.137964	36	.844862	36	133	36	29-67/97
37	.161046	37	.867573	37	137	19	10-50/97
38	.185550	38	.888743	38	141	1	51-33/97
39	.211372	39	.908282	39	144	44	32-16/97
40	.238405	40	.926108	40	148	27	12-96/97
41	.266536	41	.942148	41	152	9	53-79/97
42	.295646	42	.956333	42	155	52	34-62/97
43	.325613	43	.968603	43	159	35	15-45/97
44	.356311	44	.978909	44	163	17	56-28/97
45	.387612	45	.987205	45	167	00	37-11/97
46	.419385	46	.993458	46	170	43	17-91/97
47	.451495	47	.997642	47	174	25	58-74/97
48	.483809	48	.999738	48	178	8	39-57/97
49	.516191	49	.999738	49	181	51	20-40/97
50	.548505	50	.997642	50	185	34	1-23/97
51	.580615	51	.993458	51	189	16	42- 6/97
52	.612388	52	.987205	52	192	59	22-86/97
53	.643689	53	.978909	53	196	42	3-69/97
54	.674387	54	.968603	54	200	24	44-52/97
55	.704354	55	.956333	55	204	7	25-35/97
56	.733464	56	.942148	56	207	50	6-18/97
57	.761595	57	.926108	57	211	32	47- 1/97
58	.788628	58	.908282	58	215	15	27-81/97
59	.814450	59	.888743	59	218	58	8-64/97
60	.838954	60	.867573	60	222	40	49-47/97
61	.862036	61	.844862	61	226	23	30-30/97
62	.883600	62	.820704	62	230	6	11-13/97
63	.903555	63	.795201	63	233	48	51-93/97
64	.921817	64	.768460	64	237	31	32-76/97
65	.938309	65	.740593	65	241	14	13-59/97
66	.952964	66	.711717	66	244	56	54-42/97
67	.965718	67	.681952	67	248	39	35-25/97
68	.976519	68	.651425	68	252	22	16- 8/97
69	.985321	69	.620262	69	256	4	56-88/97
70	.992088	70	.588596	70	259	47	37-71/97
71	.996791	71	.556557	71	263	30	18-54/97
72	.999410	72	.524281	72	267	12	59-37/97
73	.999934	73	.491903	73	270	55	40-20/97
74	.998362	74	.459560	74	274	38	21- 3/97
75	.994699	75	.427386	75	278	21	1-83/97
76	.988961	76	.395516	76	282	3	42-66/97
77	.981173	77	.364085	77	285	46	23-49/97
78	.971366	78	.333224	78	289	29	4-32/97
79	.959582	79	.303062	79	293	11	45-15/97
80	.945870	80	.273726	80	296	54	25-95/97
81	.930289	81	.245340	81	300	37	6-78/97
82	.912902	82	.218021	82	304	19	47-61/97
83	.893784	83	.191886	83	308	2	28-44/97
84	.873014	84	.167042	84	311	45	9-27/97
85	.850679	85	.143596	85	315	27	50-10/97
86	.826874	86	.121644	86	319	10	30-90/97
87	.801697	87	.101278	87	322	53	11-73/97
88	.775255	88	.082586	88	326	35	52-56/97
89	.747659	89	.065644	89	330	18	33-39/97
90	.719024	90	.050524	90	334	1	14-22/97
91	.689470	91	.037289	91	337	43	55- 5/97
92	.659121	92	.025995	92	341	26	35-85/97
93	.628106	93	.016690	93	345	9	16-68/97
94	.596552	94	.009411	94	348	51	57-51/97
95	.564594	95	.004190	95	352	34	38-34/97
96	.532365	96	.001049	96	356	17	19-17/97
97	.500000	97	.000000	97	360	0	0

98 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

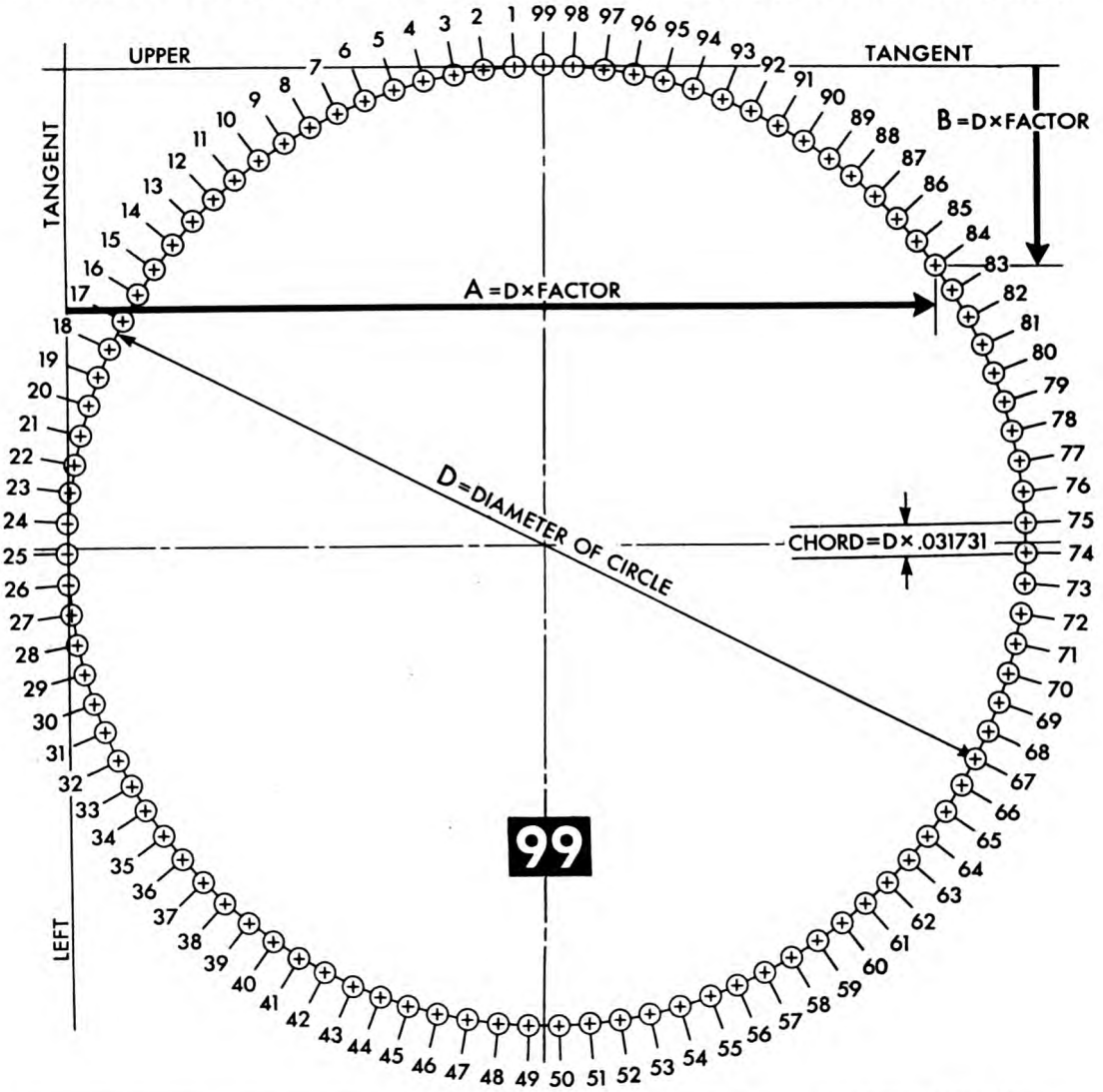


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.467965	1	.001027	1	3	40	24–48/98
2	.436061	2	.004105	2	7	20	48–96/98
3	.404421	3	.009220	3	11	1	13–46/98
4	.373175	4	.016353	4	14	41	37–94/98
5	.342447	5	.025472	5	18	22	2–44/98
6	.312367	6	.036542	6	22	2	26–92/98
7	.283058	7	.049516	7	25	42	51–42/98
8	.254641	8	.064341	8	29	23	15–90/98
9	.227233	9	.080956	9	33	3	40–40/98
10	.200945	10	.099293	10	36	44	4–88/98
11	.175886	11	.119277	11	40	24	29–38/98
12	.152159	12	.140825	12	44	4	53–86/98
13	.129860	13	.163850	13	47	45	18–36/98
14	.109084	14	.188255	14	51	25	42–84/98
15	.089914	15	.213942	15	55	6	7–34/98
16	.072429	16	.240804	16	58	46	31–82/98
17	.056700	17	.268731	17	62	26	56–32/98
18	.042794	18	.297608	18	66	7	20–80/98
19	.030766	19	.327318	19	69	47	45–30/98
20	.020666	20	.357736	20	73	28	9–78/98

COORDINATE FACTORS AND ANGLES—98 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
21	.012536	21	.388740	21	77	8	34-28/98
22	.006409	22	.420200	22	80	48	58-76/98
23	.002310	23	.451988	23	84	29	23-26/98
24	.000257	24	.483972	24	88	9	47-74/98
25	.000257	25	.516028	25	91	50	12-24/98
26	.002310	26	.548012	26	95	30	36-72/98
27	.006409	27	.579800	27	99	11	1-22/98
28	.012536	28	.611260	28	102	51	25-70/98
29	.020666	29	.642264	29	106	31	50-20/98
30	.030766	30	.672682	30	110	12	14-68/98
31	.042794	31	.702392	31	113	52	39-18/98
32	.056700	32	.731269	32	117	33	3-66/98
33	.072429	33	.759196	33	121	13	28-16/98
34	.089914	34	.786058	34	124	53	52-64/98
35	.109084	35	.811745	35	128	34	17-14/98
36	.129861	36	.836150	36	132	14	41-62/98
37	.152159	37	.859175	37	135	55	6-12/98
38	.175886	38	.880723	38	139	35	30-60/98
39	.200945	39	.900707	39	143	15	55-10/98
40	.227233	40	.919044	40	146	56	19-58/98
41	.254641	41	.935659	41	150	36	44- 8/98
42	.283058	42	.950484	42	154	17	8-56/98
43	.312367	43	.963458	43	157	57	33- 6/98
44	.342447	44	.974528	44	161	37	57-54/98
45	.373175	45	.983647	45	165	18	22- 4/98
46	.404421	46	.990780	46	168	58	46-52/98
47	.436061	47	.995895	47	172	39	11- 2/98
48	.467965	48	.998973	48	176	19	35-50/98
49	.500000	49	1.000000	49	180	00	00000000
50	.532035	50	.998973	50	183	40	24-48/98
51	.563939	51	.995895	51	187	20	48-96/98
52	.595579	52	.990780	52	191	1	13-46/98
53	.626825	53	.983647	53	194	41	37-94/98
54	.657553	54	.974528	54	198	22	2-44/98
55	.687634	55	.963458	55	202	2	26-92/98
56	.716942	56	.950484	56	205	42	51-42/98
57	.745359	57	.935659	57	209	23	15-90/98
58	.772767	58	.919044	58	213	3	40-40/98
59	.799055	59	.900707	59	216	44	4-88/98
60	.824114	60	.880723	60	220	24	29-38/98
61	.847841	61	.859175	61	224	4	53-86/98
62	.870139	62	.836150	62	227	45	18-36/98
63	.890916	63	.811745	63	231	25	42-84/98
64	.910086	64	.786058	64	235	6	7-34/98
65	.927571	65	.759196	65	238	46	31-82/98
66	.943300	66	.731269	66	242	26	56-32/98
67	.957206	67	.702392	67	246	7	20-80/98
68	.969234	68	.672682	68	249	47	45-30/98
69	.979334	69	.642264	69	253	28	9-78/98
70	.987464	70	.611260	70	257	8	34-28/98
71	.993591	71	.579800	71	260	48	58-76/98
72	.997690	72	.548012	72	264	29	23-26/98
73	.999743	73	.516028	73	268	9	47-74/98
74	.999743	74	.483972	74	271	50	12-24/98
75	.997690	75	.451988	75	275	30	36-72/98
76	.993591	76	.420200	76	279	11	1-22/98
77	.987464	77	.388740	77	282	51	25-70/98
78	.979334	78	.357736	78	286	31	50-20/98
79	.969234	79	.327318	79	290	12	14-68/98
80	.957206	80	.297608	80	293	52	39-18/98
81	.943300	81	.268731	81	297	33	3-66/98
82	.927571	82	.240804	82	301	13	28-16/98
83	.910086	83	.213942	83	304	53	52-64/98
84	.890916	84	.188255	84	308	34	17-14/98
85	.870139	85	.163850	85	312	14	41-62/98
86	.847841	86	.140825	86	315	55	6-12/98
87	.824114	87	.119277	87	319	35	30-60/98
88	.799055	88	.099293	88	323	15	55-10/98
89	.772767	89	.080956	89	326	56	19-58/98
90	.745359	90	.064341	90	330	36	44- 8/98
91	.716942	91	.049516	91	334	17	8-56/98
92	.687634	92	.036542	92	337	57	33- 6/98
93	.657553	93	.025472	93	341	37	57-54/98
94	.626825	94	.016353	94	345	18	22- 4/98
95	.595579	95	.009220	95	348	58	46-52/98
96	.563939	96	.004105	96	352	39	11- 2/98
97	.532035	97	.001027	97	356	19	35-50/98
98	.500000	98	.000000	98	360	0	0

99 HOLE DIVISION—COORDINATE FACTORS AND ANGLES

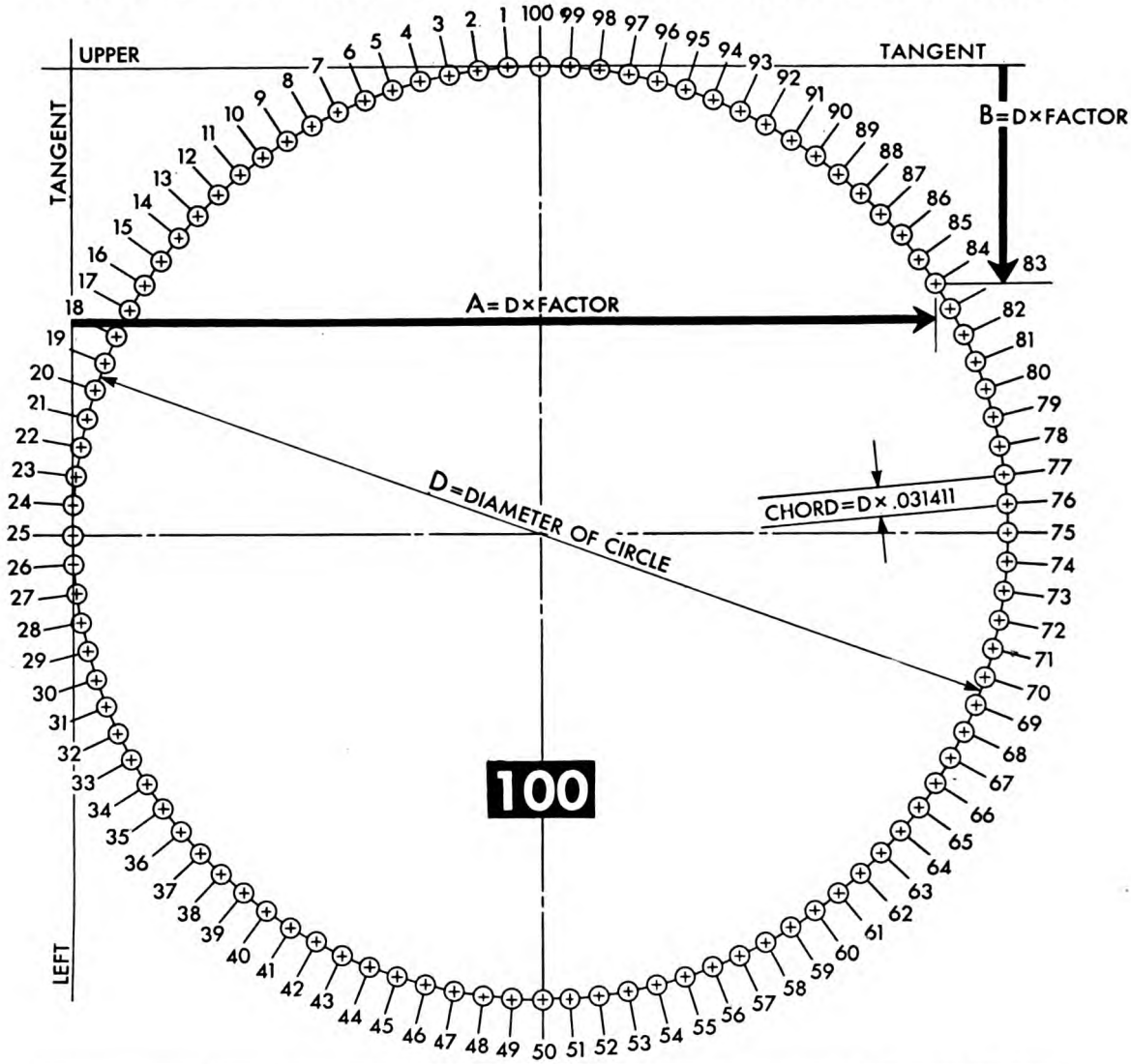


→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.468290	1	.001007	1	3	38	10–90/99
2	.436704	2	.004023	2	7	16	21–81/99
3	.405374	3	.009036	3	10	54	32–72/99
4	.374426	4	.016026	4	14	32	43–63/99
5	.343983	5	.024964	5	18	10	54–54/99
6	.314169	6	.035816	6	21	49	5–45/99
7	.285103	7	.048537	7	25	27	16–36/99
8	.256902	8	.063075	8	29	5	27–27/99
9	.229680	9	.079373	9	32	43	38–18/99
10	.203546	10	.097365	10	36	21	49– 9/99
11	.178606	11	.116978	11	40	00	00000000
12	.154961	12	.138133	12	43	38	10–90/99
13	.132704	13	.160745	13	47	16	21–81/99
14	.111927	14	.184724	14	50	54	32–72/99
15	.092712	15	.209972	15	54	32	43–63/99
16	.075138	16	.236387	16	58	10	54–54/99
17	.059273	17	.263864	17	61	49	5–45/99
18	.045184	18	.292292	18	65	27	16–36/99
19	.032926	19	.321557	19	69	5	27–27/99
20	.022549	20	.351540	20	72	43	38–18/99

COORDINATE FACTORS AND ANGLES—99 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
21	.014094	21	.382121	21	76	21	49- 9/99
22	.007596	22	.413176	22	80	00	00000000
23	.003081	23	.444581	23	83	38	10-90/99
24	.000566	24	.476209	24	87	16	21-81/99
25	.000063	25	.507933	25	90	54	32-72/99
26	.001573	26	.539625	26	94	32	43-63/99
27	.005089	27	.571157	27	98	10	54-54/99
28	.010599	28	.602403	28	101	49	5-45/99
29	.018079	29	.633237	29	105	27	16-36/99
30	.027500	30	.663534	30	109	5	27-27/99
31	.038823	31	.693173	31	112	43	38-18/99
32	.052003	32	.722033	32	116	21	49- 9/99
33	.066987	33	.750000	33	120	00	00000000
34	.083715	34	.776960	34	123	38	10-90/99
35	.102119	35	.802805	35	127	16	21-81/99
36	.122125	36	.827430	36	130	54	32-72/99
37	.143653	37	.850737	37	134	32	43-63/99
38	.166616	38	.872632	38	138	10	54-54/99
39	.190921	39	.893027	39	141	49	5-45/99
40	.216470	40	.911838	40	145	27	16-36/99
41	.243161	41	.928992	41	149	5	27-27/99
42	.270887	42	.944418	42	152	43	38-18/99
43	.299535	43	.958054	43	156	21	49- 9/99
44	.328990	44	.969846	44	160	00	00000000
45	.359134	45	.979746	45	163	38	10-90/99
46	.389845	46	.987715	46	167	16	21-81/99
47	.420999	47	.993719	47	170	54	32-72/99
48	.452472	48	.997736	48	174	32	43-63/99
49	.484136	49	.999748	49	178	10	54-54/99
50	.515864	50	.999748	50	181	49	5-45/99
51	.547528	51	.997736	51	185	27	16-36/99
52	.579001	52	.993719	52	189	5	27-27/99
53	.610155	53	.987715	53	192	43	38-18/99
54	.640866	54	.979746	54	196	21	49- 9/99
55	.671010	55	.969846	55	200	00	00000000
56	.700465	56	.958054	56	203	38	10-90/99
57	.729113	57	.944418	57	207	16	21-81/99
58	.756839	58	.928992	58	210	54	32-72/99
59	.783530	59	.911839	59	214	32	43-63/99
60	.809080	60	.893027	60	218	10	54-54/99
61	.833385	61	.872632	61	221	49	5-45/99
62	.856347	62	.850737	62	225	27	16-36/99
63	.877875	63	.827430	63	229	5	27-27/99
64	.897881	64	.802805	64	232	43	38-18/99
65	.916285	65	.776960	65	236	21	49- 9/99
66	.933013	66	.750000	66	240	00	00000000
67	.947997	67	.722033	67	243	38	10-90/99
68	.961177	68	.693173	68	247	16	21-81/99
69	.972500	69	.663534	69	250	54	32-72/99
70	.981921	70	.633237	70	254	32	43-63/99
71	.989401	71	.602403	71	258	10	54-54/99
72	.994911	72	.571157	72	261	49	5-45/99
73	.998427	73	.539625	73	265	27	16-36/99
74	.999937	74	.507933	74	269	5	27-27/99
75	.999434	75	.476209	75	272	43	38-18/99
76	.996919	76	.444581	76	276	21	49- 9/99
77	.992404	77	.413176	77	280	00	00000000
78	.985906	78	.382121	78	283	38	10-90/99
79	.977451	79	.351540	79	287	16	21-81/99
80	.967074	80	.321557	80	290	54	32-72/99
81	.954816	81	.292292	81	294	32	43-63/99
82	.940727	82	.263864	82	298	10	54-54/99
83	.924862	83	.236387	83	301	49	5-45/99
84	.907288	84	.209972	84	305	27	16-36/99
85	.888073	85	.184724	85	309	5	27-27/99
86	.867296	86	.160745	86	312	43	38-18/99
87	.845039	87	.138133	87	316	21	49- 9/99
88	.821394	88	.116978	88	320	00	00000000
89	.796454	89	.097365	89	323	38	10-90/99
90	.770320	90	.079373	90	327	16	21-81/99
91	.743098	91	.063075	91	330	54	32-72/99
92	.714897	92	.048537	92	334	32	43-63/99
93	.685831	93	.035816	93	338	10	54-54/99
94	.656017	94	.024964	94	341	49	5-45/99
95	.625574	95	.016026	95	345	27	16-36/99
96	.594626	96	.009036	96	349	5	27-27/99
97	.563296	97	.004023	97	352	43	38-18/99
98	.531710	98	.001007	98	356	21	49- 9/99
99	.500000	99	.000000	99	360	00	0

100 HOLE DIVISION—COORDINATE FACTORS AND ANGLES



→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE DEG.	MIN.	SEC.
1	.468605	1	.000987	1	3	36	0
2	.437333	2	.003943	2	7	12	0
3	.406309	3	.008856	3	10	48	0
4	.375655	4	.015708	4	14	24	0
5	.345492	5	.024472	5	18	00	0
6	.315937	6	.035112	6	21	36	0
7	.287110	7	.047586	7	25	12	0
8	.259123	8	.061847	8	28	48	0
9	.232087	9	.077836	9	32	24	0
10	.206107	10	.095492	10	36	00	0
11	.181288	11	.114743	11	39	36	0
12	.157726	12	.135516	12	43	12	0
13	.135516	13	.157726	13	46	48	0
14	.114743	14	.181288	14	50	24	0
15	.095492	15	.206107	15	54	00	0
16	.077836	16	.232087	16	57	36	0
17	.061847	17	.259123	17	61	12	0
18	.047586	18	.287110	18	64	48	0
19	.035112	19	.315937	19	68	24	0
20	.024472	20	.345492	20	72	00	0

COORDINATE FACTORS AND ANGLES—100 HOLE DIVISION

→	FACTOR FOR "A"	FACTOR FOR "B"	↓	ANGLE OF HOLE		
				DEG.	MIN.	SEC.
21	.015708	21	.375655	21	75	36	0
22	.008856	22	.406309	22	79	12	0
23	.003943	23	.437333	23	82	48	0
24	.000987	24	.468605	24	86	24	0
25	.000000	25	.500000	25	90	00	0
26	.000987	26	.531395	26	93	36	0
27	.003943	27	.562667	27	97	12	0
28	.008856	28	.593691	28	100	48	0
29	.015708	29	.624345	29	104	24	0
30	.024472	30	.654508	30	108	00	0
31	.035112	31	.684062	31	111	36	0
32	.047586	32	.712890	32	115	12	0
33	.061847	33	.740877	33	118	48	0
34	.077836	34	.767913	34	122	24	0
35	.095492	35	.793893	35	126	00	0
36	.114743	36	.818712	36	129	36	0
37	.135516	37	.842274	37	133	12	0
38	.157726	38	.864484	38	136	48	0
39	.181288	39	.885257	39	140	24	0
40	.206107	40	.904508	40	144	00	0
41	.232087	41	.922164	41	147	36	0
42	.259123	42	.938153	42	151	12	0
43	.287110	43	.952414	43	154	48	0
44	.315937	44	.964888	44	158	24	0
45	.345492	45	.975528	45	162	00	0
46	.375655	46	.984292	46	165	36	0
47	.406309	47	.991144	47	169	12	0
48	.437333	48	.996057	48	172	48	0
49	.468605	49	.999013	49	176	24	0
50	.500000	50	1.000000	50	180	00	0
51	.531395	51	.999013	51	183	36	0
52	.562667	52	.996057	52	187	12	0
53	.593691	53	.991144	53	190	48	0
54	.624345	54	.984292	54	194	24	0
55	.654508	55	.975528	55	198	00	0
56	.684062	56	.964888	56	201	36	0
57	.712890	57	.952414	57	205	12	0
58	.740877	58	.938153	58	208	48	0
59	.767913	59	.922164	59	212	24	0
60	.793893	60	.904508	60	216	00	0
61	.818712	61	.885257	61	219	36	0
62	.842274	62	.864484	62	223	12	0
63	.864484	63	.842274	63	226	48	0
64	.885257	64	.818712	64	230	24	0
65	.904508	65	.793893	65	234	00	0
66	.922164	66	.767913	66	237	36	0
67	.938153	67	.740877	67	241	12	0
68	.952414	68	.712890	68	244	48	0
69	.964888	69	.684062	69	248	24	0
70	.975528	70	.654508	70	252	00	0
71	.984292	71	.624345	71	255	36	0
72	.991144	72	.593691	72	259	12	0
73	.996057	73	.562667	73	262	48	0
74	.999013	74	.531395	74	266	24	0
75	1.000000	75	.500000	75	270	00	0
76	.999013	76	.468605	76	273	36	0
77	.996057	77	.437333	77	277	12	0
78	.991144	78	.406309	78	280	48	0
79	.984292	79	.375655	79	284	24	0
80	.975528	80	.345492	80	288	00	0
81	.964888	81	.315937	81	291	36	0
82	.952414	82	.287110	82	295	12	0
83	.938153	83	.259123	83	298	48	0
84	.922164	84	.232087	84	302	24	0
85	.904508	85	.206107	85	306	00	0
86	.885257	86	.181288	86	309	36	0
87	.864484	87	.157726	87	313	12	0
88	.842274	88	.135516	88	316	48	0
89	.818712	89	.114743	89	320	24	0
90	.793893	90	.095492	90	324	00	0
91	.767913	91	.077836	91	327	36	0
92	.740877	92	.061847	92	331	12	0
93	.712890	93	.047586	93	334	48	0
94	.684062	94	.035112	94	338	24	0
95	.654508	95	.024472	95	342	00	0
96	.624345	96	.015708	96	345	36	0
97	.593691	97	.008856	97	349	12	0
98	.562667	98	.003943	98	352	48	0
99	.531395	99	.000987	99	356	24	0
100	.500000	100	.000000	100	360	0	0

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J. Robert Moore

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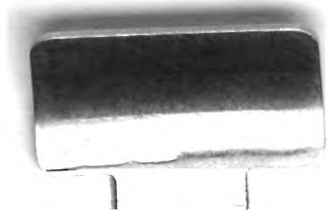

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